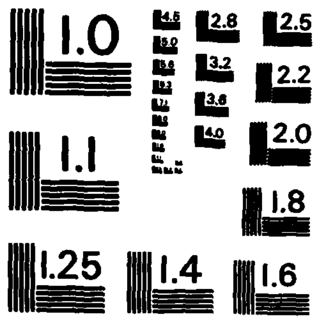
AD-A148 483 COST ESTIMATING MODELS FOR ELECTRONIC WARFARE EQUIPMENT 1/2
FLIGHT TESTS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON
AFB OH SCHOOL OF SYST.. C L HANNA ET AL. SEP 84

UNCLASSIFIED AFIT/GSM/LSY/84S-15 F/G 14/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

COST ESTIMATING MODELS FOR ELECTRONIC WARFARE EQUIPMENT FLIGHT TESTS

THESIS

Charles L. Hanna
Captain, USAF

John R. Ward
Captain, USAF

AFIT/GSM/LSY/84S-15

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSY/84S-15

COST ESTIMATING MODELS FOR ELECTRONIC WARFARE EQUIPMENT FLIGHT TESTS

THESIS

Charles L. Hanna
Captain, USAF

John R. Ward
Captain, USAF

AFIT/GSM/LSY/84S-15

Approved for public release; distribution unlimited

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the authors and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GSM/LSY/84S-15

COST ESTIMATING MODELS FOR ELECTRONIC WARFARE EQUIPMENT FLIGHT TESTS

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

Charles L. Hanna, B.A.
Captain, USAF

John R. Ward, B.S.
Captain, USAF

September 1984

Approved for public release; distribution unlimited

Acknowledgments

We wish to express our sincere appreciation and gratitude to our wives Janice and Terri, and our children, for having the patience and understanding to see us all through this project. We also wish to thank our thesis advisors Dr. Brahmanand Nagarsenker and Dr. Panna Nagarsenker and also Ms. Jane Robbins, our technical advisor for their encouragement and guidance during this project. Thanks also to Mrs. Dee Stevens for her expert typing assistance. A special thanks goes to Mr. John Killingsworth whose timely aid in data collection was invaluable to the completion of this project.

Table of Contents

Page

List of Figures

AFIT/GSM/LSY/84S-15

Abstract

The project manager is responsible for the cost, schedule and performance of assigned projects. In particular, the cost of a program is under constant scrutiny from the initiation of the program to completion. To ascertain the cost effectiveness of the program, a cost estimate must be derived that will act as the cost baseline throughout the program. The initial cost estimate is extremely important because the estimate is used to determine the appropriation of funds for project completion. Inaccurate cost estimates are detrimental to the project and the project manager's capability to manage the project effectively. The paper will describe an innovative approach to cost estimating that increases the overall accuracy of a cost estimate while requiring no more manpower than previous methods.

Program managers in the Reconnaissance/Electronic Warfare Program Office at Wright-Patterson Air Force Base, Ohio are responsible for the development of electronic warfare equipment that will protect and enhance the effectiveness of weapon systems in future conflicts. Electronic warfare systems are critical to mission success in the battle area. With expanding government budget deficits, program managers of electronic warfare systems are tasked with the responsibi-

lity of procurement of effective and efficient systems that must operate for several years after they are conceptualized.

Total system costs must be estimated well in advance of program initiation and prior to Congressional appropriations approval. Presently, no satisfactory estimating model has been developed to estimate these flight test costs. Without the benefit of accurate estimates for flght test costs government funds may be inappropriately budgeted; the result may be investment in systems that are less cost-effective than a competing system that could accomplish the same objectives. To facilitate project decisions, project manager's must be provided with accurate flight test cost estimate The problem of cost estimating flight test costs s explored. The procedures of data collection, data normaliz tion, model selection and model development were used to find a cost estimating model for electronic warfare equipment flight test costs.

The data collected consisted of historical flight test costs and system characteristics (weight, volume, type system, etc.) for previously developed and fielded electronic warfare systems. Next, the data was normalized (inflation was accounted for). The data was examined for appropriate model selection. Both parametric and nonparametric techniques were explored. The techniques considered appropriate were linear regression and principal component analysis.

COST ESTIMATING MODELS FOR ELECTRONIC WARFARE EQUIPMENT FLIGHT TESTS

I. Introduction

Accurate and timely cost estimates are an integral part of all acquisition processes (15:1). A cost estimate is the "expected dollar cost to perform a stipulated task or to acquire an item" (15:4). In particular, a requirement existed for the Reconnaissance/Electronic Warfare Program Office at Wright-Patterson Air Force Base (AFB) to estimate flight test costs for electronic warfare equipment (2). Thus, the flight test costs (costs incurred to insure system performance and reliability when placed on an air vehicle [13]) were to be estimated for electronic warfare equipment. Electronic warfare equipment is military equipment used to exploit, reduce, prevent, or intercept the hostile use of the electromagnetic spectrum (21:4). The electromagnetic spectrum may be considered as a continuum from extremely short wave lengths (.001 angstroms) to extremely long wave lengths (1,000,000 kilometers) which includes visible light, heat, as well as radar and radio frequencies (25:460).

To meet budget requirements, the flight test costs must be estimated up to six years in advance of the actual testing (2). As a consequence, accurate cost estimates were required to insure appropriate decisions could be made in the allocation of funds for future projects. There was no formally

recognized and endorsed procedure to estimate the flight test costs for electronic warfare equipment. Therefore, the possibility existed that future defense dollars might have been inappropriatly budgeted, causing the waste of government funds or lack of vital testing.

Problem Statement

The problem considered was to develop a cost estimating model capable of estimating electronic warfare equipment flight test costs up to six years prior to actual testing. Several reasons were identified as causes of the problem. First, a six-year estimate required the cost estimates to be developed for systems that were not fully designed or in some cases not even fully defined. Usually, only general knowledge was known about the system to be developed (for example, perhaps only the enemy system to be countered would be known--the enemy dictated the requirement [30:119]). In addition, occasionally only the general type of equipment was known. Examples of the types of equipment were active electronic countermeasures (radiating devices), passive measures (nonradiating devices such as radar warning receivers), and electromechanical devices (chaff and flare dispensers) (18:7). Thus, the estimating requirement was complicated by the need to estimate for a wide range of equipment from simple electromechanical devices to highly complex active jamming and passive receiving systems. Finally, the electronic warfare field was characterized by rapid technological advancements (18:9,17:1). These rapid technological advances

made the cost estimating process very difficult (2,41).

Literature Review

The explosion of electronic technological advance over the past three decades has had a profound impact on the development of electronic warfare equipment in the United States Air Force (USAF). The lead over the Soviet Union in electronic warfare equipment allows the USAF "to maneuver . . limited forces to critical points on the battlefield. Without them [electronic warfare equipment] we would not be able to prevail against the numerical imbalance we face" (12:130). The increasing electronic threat and the corresponding vital role of electronic warfare equipment has (and will) lead to increased expenditures on electronic warfare equipment. In fiscal year (FY) 1981, $332.7 million (36.3%) of the $884.5 million Research Development, Test and Evaluation budget was spent on Test and Evaluation (12:138).

The increased technological complexity of the threat required a similar increase in the technological complexity of future electronic warfare equipment. With the increased advances in technology, more flight testing will be required. "Test and Evaluation is a critical step in the aquisition process. Well planned and executed testing can detect and evaluate problems before they appear as deficiencies in deployed systems (12:139)."

The increased defense dollars to be spent on electronic warfare systems dictated a need for development of a valid method to predict electronic warfare system costs. As the

total Research and Development costs continued to increase, better and longer range Research and Development cost estimates were required to evaluate individual weapon system proposals and to estimate the funding requirements of projected force structures (37:1). Flight test costs are a significant part of this estimate (37:5). Furthermore, the avionics (which includes electronic warfare equipment) test evaluation flights are the most expensive since they require extensive range ground tracking support and often use aircraft as radar targets (6:2).

The frequent changes in funding of specific weapon systems and the numerous design and technological changes required to ensure a system can successfully counter the improving enemy weapon systems suggest that "the matter of uncertainty is a very real problem in cost analysis of future military systems and forces" (40:265). This problem of uncertainty was even more significant when the complexity variance between electronic warfare equipment was considered.

The result of the uncertainty in cost analysis of military systems in general and electronic warfare systems in particular has been large unpredicted cost overruns. From FY-1975 to FY-1980 the unexplained average total system costs (cost overruns) varied from a low of 70% to a high of 78% (31:9). According to John Allen, Directorate of Program Control for Electronic Warfare equipment in Aeronautical Systems Division Air Force Systems command, the estimates for flight test costs of electronic warfare equipment were often

in error by at least 200% (2). These flight test cost overruns were major contributing factors to cost overruns on several electronic warfare systems, including the Low Altitude Night Terrain Infrared Navigation System project.

Specific 'macro' level reasons for the cost overruns have been identified as "inflation, technical changes, quantity decreases, overoptimism and 'buy-ins' and reduced DOD budget" (10:105). Flight test costs are one of the cost elements which have led to cost overruns. Reasons for the flight test cost overruns are not well substantiated. One reason given for erroneous flight test cost predictions was that:

> Costs of instrumenting a test vehicle are largely dependent upon the specific test objectives planned for that particular vehicle. Non-basic packages of instruments are assembled to satisfy specific flight test objectives and the package is usually installed at the test site. It is the cost of this set of instruments and its' installation that are included here, and that cost varies considerably--- [37:48].

Capt Philip Linke, an Electronic Warfare Officer and flight test manager in the 4950th Test Wing at Wright-Patterson AFB, indicated that numerous items can lead to wide cost variations among different weapon system tests (29). Among the items Capt Linke listed as elements which fostered large cost variations were that the agency using the test range facilities (normally at Edwards AFB, California; Nellis AFB, Nevada; or Eglin AFB, Florida) was required to pay for scheduled test range time regardless of inflight or weather aborts that precluded the test aircraft from meeting the

scheduled test time. Capt Linke also pointed out that the test aircraft for an electronic warfare system may range from a relatively inexpensive T-38 or T-39 aircraft to a much more expensive NC-135 or C-141 aircraft.

Another reason for the large variation in flight test costs was that:

> Frequently, comparison must be made between hardware items which are not similar, or comparable on the basis of one measurement. Relative complexity must be identified. Several of the factors which may aid in the determination of this complexity are: size, volume, weight, density, type of materials, number of parts, and performance parameters [1:30].

David Benoy (7:2), John Allen (2), and Jane Robbins (41) concur and a review of all available literature substantiates that no accurate measurement tool has been developed to estimate flight test costs of electronic warfare equipment. The previously mentioned factors of electronic warfare systems'technological complexity, electronic warfare systems' diversity (size, weight, volume, density, type of materials, number of parts, and performance parameters), and the variability of costs associated with test range use were all indicated as factors which contributed to the lack of development of a reliable model to estimate flight test costs (2; 10:105; 20; 23; 27; 30; 41).

Operational Definitions

Following are key operational definitions not previously given:

1. Reimbursable flight test costs: costs incurred by a program office as a result of requested testing (29). In the last several years program offices have absorbed increasing proportions of cost center expenses; currently almost all flight test "cost center expenses are reimbursable with the exception of military labor and normal base support functions" (7:1). In this thesis the term "flight test costs" will refer to the flight test center costs incurred in support of electronic warfare equipment testing that can be charged as reimbursable expenses to the program office responsible for the development of the specific electronic warfare equipment being tested.

2. Electronic warfare equipment: military equipment used "to prevent or reduce an enemy's effective use of radiated electromagnetic energy and actions taken to insure our own effective use of radiated electromagnetic energy" (45:250).

3. Electronic warfare equipment categories: electronic warfare equipment is extremely diversified and was qualitatively divided in order that cost factors could be objectively analyzed. Four sub-categories of electronic equipment were defined:

a. Receivers: electronic warfare equipment designed to intercept, interpret and display electronic signals in order that the position and danger posed by enemy radars may be known (21:3).

b. Jammers: electronic warfare equipment designed

to deceive and disrupt enemy radars by noise, barrage or repeater signal scrambling (21:3).

c. Dispensers: electronic warfare equipment designed to deceive enemy radars and missiles through the use of chaff and flare deployment (21:4).

4. Key flight test site cost elements:

a. Test Vehicle Fabrication: the cost of flight test vehicles during the Research and Development period (37:9).

b. Test Operations: those activities associated with flight testing vehicles required by the development program (37:9).

c. Test Ground Support Equipment: that equipment required at the test sites for flight test activities (37:9).

d. Test Instrumentation: test vehicles designed to collect data required by the test objectives (37:10).

e. Fuels, Propellants and Gases: "the fuels, propellants and gases used during flight test operations" (37:10).

f. Data Reduction and Analysis: "the activities associated with the processing for analysis and study the measurements of performance recorded during developmental, captive, and flight test operations" (37:10).

g. Maintenance, Supply, Miscellaneous: "those activities associated with maintenance and supply of test vehicles, test ground support equipment, and installa-

tions and facilities" (37:10).

5. Cost Estimating Relationships: "An analytical expression which describes, for predictive purposes,the quantity or cost of an item or activity (either in physical units or dollars) as a function of one or more explanatory variables" (15:4).

6. Coefficient of Determination (R2): A measurement of the proportionate reduction in total variation in a dependent variable that can be explained by the use of independent variable(s) (28:97,241).

7. Independent Variable: The variables that influence or that can be used to predict the flight test costs of electronic warfare equipment.

8. Dependent Variable: The variable we are interested in measuring; in this research project the dependent variable is the flight test costs of electronic warfare equipment that are chargeable to the program office responsible for the development of the electronic warfare system.

9.Collinearity: The correlation among independent variables (28:272).

Scope

A prediction model was designed which used the reimbursable costs that a program office incurs in the development and testing of electronic warfare equipment. The model was tailored to the needs of the Electronic Warfare System Program Office, Aeronautical Systems Division, Wright-Patterson AFB. The model was tailored for one or more of the

electronic equipment categories (receivers, jammers, dispenser). The model employed only those input prediction factors which could be clearly defined or accurately estimated as early as six years prior to the date the flight test costs were to occur.

Research Questions

The following are the germane research questions formulated for the problem of estimating long range flight test costs for electronic warfare equipment:

1. Does the historical data available represent the population to be predicted?

2. Are the cost estimating (causal) relationships predicted by experts in the field consistent with the data collected?

3. What type of model is the most appropriate for this problem?

4. Which explanatory variables can be identified to predict flight test costs?

5. How accurately can electronic warfare flight test costs be predicted with the model and variables selected?

6. Can the model be validated?

7. Does the model fulfill the needs of the Reconnaissance/Electronic Warfare Systems Program Office?

Availability of Data

Data was obtained from the Aeronautical Systems Division

(ASD) cost library; the flight test ranges (Edwards AFB, California; Eglin AFB, Florida; and Nellis AFB, Nevada); the ASD Systems Program Offices at Wright-Patterson AFB, Ohio; the 4950th Flight Test Wing at Wright-Patterson AFB, Ohio, and from an unpublished thesis by Thomas J. DuPre'.

The ASD cost library had a number of documents with required data. The most noteworthy published data base was the September 1980 Rand Corporation document Special Duty and Combat Avionics Data Base(s) (19). The document contained an extensive list of electronic warfare equipment in the USAF inventory. Data included 100th unit cost, weight, learning curves, volume, density, and technological year for the equipment. Additional documents from which data were obtained are listed in the bibliography (3, 4, 17, 18, 19, 20, 30).

A second source of data was the flight test ranges (Edwards AFB, Eglin AFB, and Nellis AFB) where the tests were accomplished. Although useful in most cases, some of the data obtained from the test ranges were fragmented. The most reliable, comprehensive and useful data was obtained from Mr. John Killingsworth of the 3246th Test Wing at Eglin AFB, Florida. Another noteworthy source was the Management Information System Test and Evaluation (MISTE) system at Edwards AFB, California (42). The third source of data was the individual program offices of ASD at Wright-Patterson AFB, Ohio. The financial managers for each program office (one program office for each electronic warfare system developed or modi-

fied) collected and kept a detailed record of all the flight test costs for a particular system. Unfortunately, no set procedure had been established to retain the flight test cost records after an acquisition/modification program was completed (2,41). This problem is addressed in the recommendations section of this document.

The next source of data was the 4950th Test Wing at Wright-Patterson AFB, Ohio. The 4950th is responsible for the early developmental flight testing (29). Data obtained was limited to four programs because the unit also does not have an established procedure for maintaining historical flight test costs (9).

The final data source was the unpublished thesis by Lt Thomas J. DuPre'. The data contained in the document had been obtained from some of the previously mentioned sources (20).

II. Background

Flight test costs are the reimbursable costs that are charged to a program office as the result of a test flight activity (7:1). The following will explain the sequence of events as well as the types of activities that cause flight test costs to be incurred.

First, when a program office determines a requirement exists to flight test their systems (or a part of the system) a program introduction document (PID) is submitted to an Air Force Flight Test Center. "The PID defines specific systems specifications and requirements to be tested" (7:1). Next, the PID is sent through the various offices at the Flight Test Center and estimated costs are attached for each of the requested tests. The final product is then sent back to the originating program office through a statement of capability (SOC). This document (SOC) indicates to the program office the expected costs to complete the required testing.

The following are typical costs that are incurred for flight testing (13):

1. Aircraft fuel costs (POL)
2. A cost per flying hour for all needed aircraft
3. Logistic support for all aircraft
4. Computer support
5. Engineering support
6. Range support
7. Test requirements support

8. Aircrew support (military aircrew costs are not included)

9. Photographics

10. Electronic support

11. Miscellaneous costs

The purpose of our model is to predict the aforementioned costs (the total cost for all the flight tests) well in advance of the actual determination of what tests will be needed for an acquisition/modification program.

Analytical Techniques

The difficulty of estimating the cost of electronic warfare equipment that "is characterized by rapid technological change" was the major factor in determining the analytical techniques and procedures most appropriate for resolving the problem. A brief discussion of the applicability of the techniques available illustrates the constraints that prohibited a simple solution to the problem; a detailed discussion of the specific procedures to be used is found in Chapter III.

The first requirement for any analytical technique and specifically for a cost estimating relationship is that all predicting relationships be based on logic and causality (16:16). If a causal relationship is not established between the independent variables that are used to predict the dependent variable (cost) we are interested in, the independent variables cannot be relied on to yield consistent results

over time as other factors intervene. Ideally, the technique selected would utilize predictive information from all significant factors that determine the flight test costs of electronic warfare equipment. Both nonparametric and parametric estimating techniques are currently used by Aeronautical Systems Division at Wright-Patterson AFB to estimate electronic warfare equipment costs (2). Nonparametric approaches rely on estimating costs by evaluating elementary components of a system and then summing the expense of all components to arrive at a total cost for the system (38). The nonparametric approach was judged to be inappropriate for the estimation of flight test costs of electronic warfare equipment since these estimates often must be done up to six years in advance to meet budgeting constraints. Six years prior to flight testing a system is often not fully conceptualized or defined (2) and therefore does not allow component part costs to be estimated.

Parametric approached involve the selection of independent variables which have strong causal linkages to the dependent variable or item of interest (38). In this case we were interested in the cost estimating relationships between independent variables that can be selected several years in advance of actual flight test costing and the flight test costs that actually occur. In solving this problem we must first logically determine how certain key factors will affect the development of an electronic warfare system and then estimate the funding that will be required to adequately

flight test the new system. Selecting the independent variables that accurately predict impacts on electronic warfare system development has been considered to be a difficult task:

> The choice of physical or performance characteristics for estimating the cost of a given variety of electronic warfare equipment is crucial. As already pointed out, electronic warfare equipment must be broken out into a sizeable number of homogeneous classes before valid estimating relationships can be prepared. In addition, it is rare that a single characteristic serves as an adequate measure of the equipment cost within a single class--multivariate relationships are generally required. It also appears that the range of size and performance over which a relationship is valid is limited to a considerably greater extent than is true for airframes and power plants. Thus, it is desirable in deriving electronic equipment estimating relationships to test the range of values over which these functions are usable and specify the limitations of each relationship [5:5].

It has been stated that "the primary criterion for choosing parameters for estimating is that they provide the most sensitive" measures of equipment design and that they "be readily available early in the design" (5:6). Interviews with test experts indicated that weight, density, volume, power requirements and whether or not the system developed was a modification of an old system would all impact on total equipment costs and the testing costs required to validate that system. Additionally, the specific equipment category of the system (receiver, jammer, dispenser) would all impact upon flight test costs (2;29).

A widely used parametric estimating method is the linear regression technique. A major limitation of this technique

is that if two or more important explanatory variables are collinear the regression analysis may be in serious error (35:196). With collinearity little confidence can be expressed in the prediction coefficients; collinearity can be detected by high correlation coefficients between independent variables (35:196). A preliminary statistical analysis of the data indicated high correlation coefficients between several of the important independent variables; this indicated the existence of a serious collinearity problem that would significantly limit the confidence that could be placed in any results achieved with a linear regression model.

A recent parametric technique that eliminates the effects of collinearity is the use of principal component analysis (22:38). This regression technique computes the value of dependent variables by forming an equation made up of principal components that are derived from various combinations of the original independent variables (22:38). These principal components retain all the statistical information possessed by the original independent variables but are completely free of collinearity. These principal components are then used as 'statistically pure' independent variables in an equation to estimate the value of the dependent variable (flight test costs) (22:36). Because of the major difficulties of collinearity and the limited data available, the principal component analysis method was selected as the primary analytical technique to resolve this difficult prob-

lem; the resulting capability to retain all data with informational value was essential since other techniques evaluated would have required some of the data to be discarded. A full discussion of the principal component method is in Chapter 3 (Methodology).

Assumptions

1. The less that is known about a system the more it will have to be tested to verify its capability. This will normally increase flight test costs.

2. The more an electronic warfare system changes in technology, capability or method of utilization from previous systems the more it will cost to flight test that system. This assumption follows from assumption #1.

3. Variables that explain the variability in electronic warfare system costs will also help explain the variability in electronic warfare equipment flight test costs. This assumption follows from assumption #1 and #2.

4. A qualitative variable reflecting the mean year of the years that the system was flight tested will capture the impact that (1) technological change and (2) the increases in the costs at each test site have on total flight test costs.

5. A qualitative variable reflecting the type of aircraft used for flight testing will be of value in predicting flight test costs.

6. A qualitative variable reflecting whether or not the system considered is a modification to an existing system

will be of value in predicting flight test costs. This assumption follows from assumptions #1 and #2.

7. Factors that increase the flight test costs of equipment in each of the four categories of electronic warfare equipment (receivers, jammers, missiles, and dispensers) will also help predict the increases in flight test costs of equipment in the other three electronic warfare equipment categories. This assumption follows from the similar test requirement for all categories of equipment.

Model Use

The model developed will be used by cost analysts at the Reconnaissance/Electronic Warfare Program Office at Wright-Patterson AFB to predict the flight test costs for electronic warfare equipment. The cost estimate for flight tests is only one of eight cost predictions required for a budget estimate. The other areas that costs must be estimated for are (2,20:23):

1. Prime mission equipment
2. Peculiar support equipment
3. Software
4. System integration
5. Data
6. Training
7. Mission support

At present, there are adequate techniques and models available for the preceding seven areas; however, no adequate

technique or model exists for predicting future flight test costs for electronic warfare equipment (2). Therefore, the model will be used to predict long range flight test costs that will be used for budget submissions.

III. Methodology

Data Collection

The data collected is an accurate reflection of the population for which the model was developed (2). The population consists of weapons designed to negate the electronic threat of the enemy in order that USAF air power can be maneuvered to "initial points on the battlefield" (12:130). Electronic warfare equipment will be crucial in determining the outcome of future air battles.

This research has placed electronic warfare equipment in three categories: receivers, jammers, and dispensers. Operational definitions of each type of electronic warfare equipment are found in Chapter I. Therefore, the population applicable to this research consists of all past and present electronic warfare equipment used on aircraft that can be categorized as a receiver, jammer, or dispenser.

The population under consideration evolves in response to changing Air Force requirements. Major Commands (primarily Strategic Air Command; Tactical Air Command; United States Air Forces Europe; and Pacific Air Forces) generate Statements of Operational Need that detail the requirements current or future systems must possess in order to successfully counter the threats posed by enemy capabilities (11:3-1,3-2). The Statement of Operational Need is acted upon and the foundation for the creation of a new system is completed early in the conceptual phase of the

Defense Systems Acquisition Review process (14:60). At this point a program office is normally assigned responsibility for the system. If the system is electronic warfare equipment it is often assigned to the Reconnaissance/Electronic Warfare Program Office at Wright-Patterson AFB; normally, forty to fifty separate electronic warfare system are in development under the direction of the Reconnaissance/Electronic Warfare Program Office (2). These systems comprise the major portion of additions to the population this research is concerned with although other appropriate members of the population come from the Electronic Systems Division at Hanscom Field in Boston, Massachusetts and the United States Department of Naval Operations electronic warfare projects (2).

The data collected is representative of the population of interest (2). Each of the equipment categories is represented in the sample in approximately the same porportion as it exists in the population. Additionally, our use of dummy variables to account for differences in costs in each of the equipment categories allowed some latitude in not having the sample percentages in each category exactly reflect the population percentages (see <u>Assumptions</u> #7 Chapter II). Dummy variables are independent variables used to indicate categorical differences between observations. If enough data were available an optimum predictive model could be built for each electronic warfare category.

Details of the data collection effort are found in

Chapter I, Availability of Data. The data was normalized through the use of inflation factors (all cost figures are in FY 82 dollars) and a variable that accounted for advance in the technological complexity of electronic warfare equipment (16:26). A variable was also used to indicate whether or not the electronic warfare system was a new or modified system; this measured the "learning curve" phenomenon that was assumed to exist (16:26). Additionally, the data were analyzed and adjusted to ensure the measurement indices from the different flight test centers were consistent (16:26).

In the data collection process test engineers were questioned as to what they thought the most important variables would be in predicting flight test costs. They were also asked to indicate how these independent variables would impact the flight test costs. The responses of the test engineers were instrumental in constructing the model (see Developing the Model in this chapter).

Model Selection

The main criteria for model selection were to determine whether or not the model could accurately estimate the cost of flight testing specified electronic warfare equipment and to ensure that the selected model could be used by the Reconnaissance/Electronic Warfare Program Office personnel to predict costs up to six years in advance of the flight tests.

Nonparametric techniques rely on a building block approach to cost estimating. The cost of individual subcom-

ponents and components are estimated and then summed to calculate an overall cost for the system (38). This technique cannot be used to estimate the costs of flight testing electronic warfare equipment up to six years prior to the flight testing because at the six year point in the development cycle the system is often not fully conceptualized or defined (2). The building blocks of the flight test costs cannot be calculated until the system is conceptualized and designed. Therefore, all nonparametric cost estimating techniques were eliminated because the necessary data would notbe available to the cost analysts of the Reconnaissance/ Electronic Warfare Program Office at the time flight test costs are estimated.

Parametric estimating techniques were considered primarily because indications were that the parametric methods would fulfill the criteria of being the most accurate method that could be easily implemented by the cost analysts. If "only mission and performance envelopes are defined the parametric approach is the only method that can logically be used to make an estimate" (44:3). Parametric methods are also preferred because they are recommended by the Cost Analysis Improvement Group as the preferred estimating method to be used for Department of Defense systems during the development phase (31:16). "This is intended to assure that major defense systems decisions are based on a realistic assessment of what resources a system will require; and, thus whether a given system is cost effective . . ."(44:2).

The linear regression model is a parametric technique often used by USAF cost analysts. The linear regression model can only be an accurate estimation technique if independent variables can be identified that have a strong causal linkage to the dependent variable (flight test costs) (38). After the key independent variables are identified they must also be properly specified to reflect the true relationship they have with the dependent variable (28:132-140). Major problems can occur in linear regression functions when collinearity (28:271-8, 382-400) or autocorrelation (28:444-60) occur. (Collinearity and autocorrelation are discussed in more detail in Analytical Techniques in Chapter II.) Initial tests were run on the data to determine if the linear regression model was appropriate (See *Developing the Model*, Chapter III).

Another parametric technique considered was the principal component regression method. This method is most appropriately used when collinearity exists between the independent variables, when some variables need to be eliminated because they contribute very little information, or when it is necessary to reduce "the basic demensions in the variability in the measured set" (24:235). Two main advantages are gained when the principal component regression method is used: (1) each component is free of collinearity and (2) "each component contains a maximum amount of information consistent with being uncorrelated with the previous ones" (32:255).

A major potential problem with the principal component analysis method is that since the independent "variables of the final model are linear combinations of the original explanatory variables" the independent variables in the final equation are not easily interpreted (39:177). Utilization of the principal component method will require a searching analysis to determine the appropriate interpretation of what each component is measuring.

Ridge regression is a method used to correct collinearity problems by "modifying the method of least squares to allow biased estimators of the regression coefficients" (28:394). The purpose of ridge regression is to introduce a small amount of bias in exchange for an increased precision level in the estimate of the regression coefficient. Ridge regression has been substantiated as a beneficial aid to linear regression models but has not been fully developed for use with principal component regression models (36).

Chapter III, Developing the Model, outlines the specific steps to be used in selecting the appropriate parametric model. If the linear regression model is chosen a decision will then be made as to whether ridge regression techniques are appropriate or not. If the principal component regression model is chosen, the final equation of the model is a collinear-free linear regression model; ridge regression techniques will not be used with this model. The sections in Chapter III entitled Validating the Model and Answering the Research Questions are applicable to the simple linear

regression method and the principal component regression method.

Developing the Model

The purpose of the model developed was to predict long-range flight test costs. The following steps were used to develop the model:

1. Identification of the independent variables (cost drivers)
2. Specification of the variables.
3. Manipulation of the data to observe the following:

   a. Outliers in the data
   b. Autocorrolation
   c. Collinearity between independent variables
   d. Homoscedasticity of the data

4. Linear regression analysis
5. Principal component analysis

A detailed explanation of each step will follow.

Identification. The first step in the model development was to select the appropriate independent variables (cost drivers) to be considered. In general, "the analyst attempts to identify a cause-and-effect relationship between the selected independent and dependent variables" (16:17). To find the causal (cause-and-effect) relationships, the analyst must rely on his own technical skills as well as those of the experts in the field (16:19). The technical interface between the experts in the electronic warfare procurement and

developmental field (engineers, program managers, financial managers, and flight test engineers) and the model specification was accomplished with the use of five personal interviews. Two decision rules were used in the final selection of the independent variables to be used in the modeling effort (34:32):

Rule # 1. A logical relationship must exist between the variable selected and flight test costs. In essence, a causal relationship must exist between the selected variable and the flight test costs that are to be predicted by the model.

Rule # 2. The selected variable must also describe an electronic warfare equipment characteristic identifiable by planners in the early conceptual phase.

With the use of the preceding decision rules, the following independent variables were selected: weight, density, volume, input power, type of equipment (jammer, receiver, or despenser), whether the system tested was a modification of an existing system or a completely new system, and whether the system was tested by the 4950th Test Wing (4950th usually tests projects early in the conceptual phase).

Specification. The specification step required a functional form to be selected for each of the identified independent variables. The functional form of an independent variable is determined by the behavior of the dependent variable as the independent variable changes. As an example, if weight is considered as an independent variable, then it

must be discerned (if possible) how the dependent variable (flight test costs) will change as the weight of a system being flight tested changes. The question at hand is how are flight test costs influenced by weight. Do flight test costs increase as weight increases or do the flight test costs decrease? Also, in question is at what rate do the changes occur. Thus, the question is whether the flight test cost will increase at a constant, increasing, or decreasing rate. In essence, one is attempting to find the first and second derivatives of the function:

cost = f(weight).

A detailed discussion of the specification procedures is beyond the scope of this paper but more detailed explanations of procedures are contained in references (16, 17).

One specification of note was presented by Benoy (7:3). He stated, "As costs increase as a function of some explanatory variable the rate of change should increase at a decreasing rate." The rationale was that this allowed the fixed costs associated with flight tests to be spread over all the different flight tests occuring during a period.

The decision rule for the specification of an independent variable was as follows:

Decision Rule: The specification must make logical sense and must be supported by expert opinion (expert opinions were obtained through personal interviews).

__Data Manipulation__. The data was manipulated to deter-

mine the presence of outliers, the presence of autocorrolation, the degree of collinearity present between the independent variables, and finally the degree of homoscedasticity in the data. The terms outlier, autocorrolation, collinearity and homoscedasticity will be defined when used in the following sections.

Outliers. Outliers are data points (observations) that are not representative of the population being measured (28:400). "These outlying observations may involve large residuals and often have dramatic effects on the fitted least squares regression function" (28:400). A means to evaluate outliers is to calculate the "hat" matrix and then evaluate the diagonal elements of the "hat" matrix. Kutner (28) gives a detailed explanation of both the theory and the calculations to obtain the "hat" matrix.

> Decision Rule: Each diagonal element of the "hat" matrix was compared to the value of 2p/n where p is the number of regression parameters and n is the number of diagonal elements of the "hat" matrix. If a diagonal element of the "hat" matrix is larger than the value calculated for 2p/n then that observation associated with the diagonal element is considered an outlier and a candidate for removal from the data set.

Autocorrolation. Autocorrolation occurs when the error terms of a regression model are not random, but are a function of one or more of the independent variables

(28:444). Autocorrolation is common in time series data if a key variable has been omitted (28:444). Therefore, the data was tested for autocorrolation using the Durbin-Watson test for autocorrolation. A detailed explanation of the test and procedures is contained in reference 28 pages 450-454. The value of D (the Durbin-Watson test statistic) was calculated for the Data Set using the SPSS software package.

Decision Rule: Use a Durbin-Watson test table to accept or reject the hypothesis that the data is autocorrolated.

Collinearity. Collinearity exists when there is a linear relationship between two or more independent variables (39:143). When collinearity exists, one independent variable can be written as a linear combination of one or more of the remaining independent variables. Collinearity causes increased variation in the regression coefficients (28:390). The large variations in turn can cause errors in the predictions of the dependent variable (flight test cost). Therefore, collinearity is a problem that must be recognized and taken into consideration when building a regression model. The following methods were used to discern the presence and degree of collinearity in the data set:

Test #1. Pairwise collinearity: determined by examining the correlation matrix and the values of the correlation matrix.

Decision Rule: Independent variables with correlation coefficients greater than .80 indicate excessive

collinearity and the independent variable must be transformed or eliminated (35:196).

Test #2. Regress each independent variable in turn against all the remaining independent variables and then compare the R^2 (correlation coefficient). The correlation coefficient (R^2) is "the percent of variance in the dependent variable explained by the estimating function" (16:33).

Decision Rule: same as for test #1.

Test #3. Variance Inflation Factor: Similar to test #2 above.

$$(VIF)_k = (1 - R^2{}_k)^{-1} \quad k= 1,2,..p-1$$

where $R^2{}_k$ is the coefficient or determination when X_k is regressed on the p-2 other variables

Decision Rule: Variance Inflation Factors greater than 10 are considered excessive and the independent variables must be transformed or eliminated (28:392).

Homoscedasticity. Homoscedasticity is the condition where the regression error variances are equal at all points along the regression line (35:170). The lack of homoscedasticity is known as heteroscedasticity. The condition of homoscedasticity is necessary for linear regression analysis (35:170). The following methods were used to test for homoscedasticity in the data set:

1. Scatterplots: plots of the residuals of a linear regression against each of the independent

variables as well as the dependent variable.

Decision Rule: Interpretation of scatterplots is extremely subjective. In general, each plot will be evaluated separately to determine if a visible fan shape (Figure 1) is present in the plots. Fan shapes are an indication that heteroscedasticity may be present and the data would need to be transformed. Possible transformations are in the reference by Kutner (28:170).

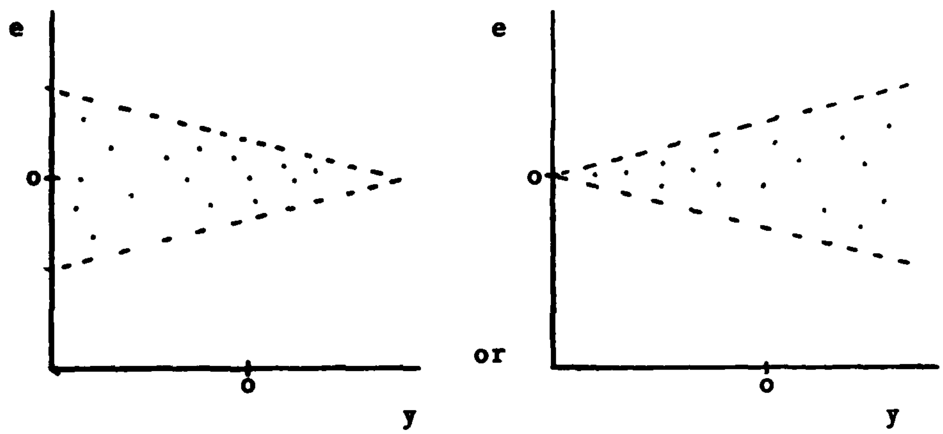


Figure 1. Fan-Shaped Scatterplots.

2. A more precise Spearman's Correlation Coefficient Test was conducted to indicate whether or not the data was homoscedastic. This test involved rank ordering each data point according to the appropriate independent variable (Rx) and also according to the size of the absolute value of the residual of the dependent variable (Ry) (33:558-562). A correlation coefficient, Rs, was then calculated as follows:

$$Rs = \frac{Rx\ Ry - (\ Rx)(\ Ry)/n}{[\ Rx^2 - (\ Rx)^2/n][\ Ry^2 - (\ Ry)^2/n]}$$

Statistical tests (33:560, 28:123) can be used to test for a heteroscedastic (non-homoscedastic) condition using the Rs value.

In the linear regression model only those variables which could be measured at an ordinal level could be tested in this way for a heteroscedastic condition because the Spearman's Correlation Coefficient Test requires a minimum of ordinal data.

Decision Rule: The hypothesis for the test is that $Rs = 0$; if $|Rs| > r_{n}, \alpha/2$ the hypothesis of $Rs=0$ will be rejected. Accepting the hypothesis will indicate that a homoscedastic condition exists. The test for homoscedasticity in this thesis used values of $n=22$ (where n equals the number of data points) and $\alpha=.10$. Therefore using the tables found in the Meek and Turner text (33:772) if a value of less .359 was calculated for Rs a condition of homoscedasticity was accepted.

Multiple Linear Regression Analysis

The fourth step in developing the model was to take the remaining data and perform multiple linear regression analysis. The purpose of multiple linear regression analysis is to identify the significant relationships between the independent variables. The relationships can be obtained if the historical data is representative of the population (flight test cost producing population) (16:25). The

assumptions required for the multiple regression analysis are as follows: (34:106)

1. The variance of the observations are equal (homoscedasticity).
2. The error terms are normally distributed.
3. The expected value of the error terms is zero.
4. Each observation is independent.

If the preceding assumptions hold, then the regression analysis "fits" a straight line (regression line) through the data points such that there is minimum variance (distance from the data point to the regression line) in the sum of the squared distances between the data points and any other possible straight line. The process used to find the "fitted" line was stepwise linear regression. "Stepwise linear regression is a method of constructing a regression equation which selects first the independent variable that contributes the most to explanation of the variation" (34:37). The process is continued until all the significant variables have been identified sequentially and brought into the regression equation. The stepwise regression was accomplished with the use of an SPSS software package. Detailed explanation of the theory of multiple linear regression analysis may be obtained from the Kunter (28) reference.

Principal Component Analysis

The final step in developing the models was to perform principal component analysis on the data set. The purpose of

the principal component analysis was to remove any remaining collinearity that might exist (24:235). The analysis was performed using a BMDP4R software package.

Principal component analysis is based on the fact that "every linear regression model can be restated in terms of a set of orthogonal explanatory variables" (39:157). Orthogonality means there are no linear relationships (collinearity) between the explanatory variables (39:143). The regression model is manipulated in the following manner to insure the independent variables are orthogonal (not collinear) (39:172-173):

1. Consider the basic linear regression model

$Y = XB + u$	where Y is an n x 1 vector of observations on the response variable
	x is an n x p matrix with n observations and p explanatory variables
	u is an n x 1 vector of the residuals (unexplained variation)
	B is a p x 1 vector of regression coefficients

2. Modeling is based on the following assumptions:

   a. $E(u)=0$ expected value of the error terms is zero

   b. $E(u\,u')=\sigma^2 I$ error terms are independent and homoscedastic (constant variance)

3. There exists a matrix C such that

   $C'(XX')C=\Lambda$ and $CC'=C'C=I$

   where Λ is a diagonal matrix with "ordered characteristic roots" of the X'X matrix on the

diagonal.

C is a matrix with columns that are normalized characteristic roots corresponding to the eigenvectors.

4. The C matrix can be used to create a new set of explanatory variables that are orthogonal as follows:

$$(W_{(1)}, W_{(2)}, \ldots W_{(p)}) = W = XC = (X_{(1)}, X_{(2)}, \ldots X_{(p)})C$$

the W's are principal components and finally the regression model may be stated as

$$Y = W = \alpha u \quad \text{where } W = XC$$

$$\alpha = C'B$$

A more detailed explanation of the procedures and theory of component analysis can be obtained from the reference by Kendall (26).

Validation

Validation Tests. In addition to the procedures outlined in the previous sections the following tests will be performed to ensure the model is valid and does not violate its underlying assumption:

1. Chi-Square Test: This test indicates whether a data set comes from a specified distribution (33:334). For the model(s) used in this research a normal distribution is required because the F and T statistical tests (below) are based on a normal distribution of the population being sampled. The Chi-Square Test will be used to test the reasonableness of the normality assumption.

2. Kolmogorov-Smirnov Test: This test can also be

used to test the assumption that sample comes from a population with a normal distribution (33:342). The Kolmogorov-Smirnov Test is more restrictive in its assumptions than the Chi-Square Test in that it was continuous rather than discrete measurement of the data (33:342). When possible this test will be used to test the reasonableness of the normality assumption.

3. Runs Test: An underlying assumption of the parametric methods and other statistical tests used in this research is that a random sample has been selected. "The runs test provides a rough check on the validity of this assumption" (33:345). The runs test will used to test for randomness on all independent variables that can be dichotomized. (Dichotomization is required for the runs test to be used [33:345].)

4. Coefficient of Determination (R^2): The coefficient of determination measures the proportionate reduction in total variation in a dependent variable associated with the use of the independent variable(s) (28:97,241). R^2 will always have a value between zero and one (inclusive). A value of zero indicates the independent variables do not explain any of the variation in the dependent variable and therefore the independent variables have no predictive value. A value of one indicates the independent variables are perfect predictors of the dependent variable. R^2 seldom takes on a value of exactly zero or one (33:97). R^2 will also

be used to indicate the degree of correlation (collinearity) between independent variables.

5. F-test: The Fisher F-test is used to measure the ratio of the regression mean square (MSR) and the error mean square (MSE) (28:88,92). MSR is the variance of the dependent variable that is explained by the independent variable(s); MSDE is the variance of the dependent variable that is not explained by the independent variable(s). The F-statistic is equal to MSR/MSE (28:92). A high F value indicates that the hypothesis that the independent variable(s) have little explanatory value is false and should be rejected; a low F value indicates that the hypothesis that the independent variable(s) have little explanatory value is true and should be accepted (28:92). The F-test was relied on to evaluate the utility of individual independent variables and the full linear regression model.

6. F-test and R^2 evaluation: When an independent variable is added to a model that already contains other independent variables the coefficient of determination (R^2) will either increase or remain constant; if R^2 was relied on as an accurate indicates of the total estimating power of a model the addition of several random independent variables could appear (erroneously) to explain the total variation of the dependent variable (28:241). However, each independent variable which is added will also influence the F-ratio. If the F-ratio

decreases (with the level of significance held constant) then the independent variable that was added to the equation decreases the precision of the estimate by a larger extent than it increases the explanatory value of the model (28:241). Therefore, this research relied primarily on the F-ratio to evaluate the significance of independent variables and used the R^2 value to determine the total explained correlation only if it (R^2) was achieved at significant F-ratios.

7. T-test: The Students T-test can be used to estimate the mean in a normally distributed population when only a sample is available to use in the calculations of the estimate (33:230). The T-test was used to estimate the coefficients of individual independent variables. A significant problem occurs when T-tests are used to predict statistical levels of significance for independent variables that are marked by collinear relationships with other independent variables (28:275-9). Therefore, T-tests were only used for intermediate judgement in building the model and not as a final authority as to the significance level of the independent variables that were used to construct the estimating model.

Validation Procedures

No data points were withheld from the model construction. Therefore, additional points must be collected before

validation can be completed.

In accordance with the needs of the Reconnaissance/Electronic Warfare Program Office the minimum acceptable criteria for estimating accuracy was set at 50% of the actual observation (2). The desired estimating accuracy was set at 10% of the actual observation; therefore, all confidence intervals were constructed with ranges equal to 10% (α =20%) of the actual observation. The requirement to estimate flight test costs up to six years in advance with limited information available justified the 50% minimum criterion and made the 10% criterion seem extremely difficult to achieve. The eigenvalues, determinants and significance levels previously noted were used to evaluate the sensitivity of the model to the input parameters (independent variables).

Answering the Research Questions

Following is a restatement of each research question and an evaluation of how the methodology provided for it to be answered:

Question #1. Does the historical data available represent the population to be predicted? The section titled Data Collection of this chapter adequately described the population and accounted for variances between the sample and the population. The parametric technique using independent variables to account for difference between the population and the sample was also discussed; these 'dummy' variables will help add predictive value to the model for members of

the population that have characteristics that are not possessed by all members of the population.

Question #2. Are the cost estimating (causal) relationships predicted by experts in the field consistent with the data collected? The methodology described in the section titled Developing the Model of this chapter will adequately answer this question. The statistical tests applied to the linear regression and principal components regression models will determine if these predicted causal relationships are statistically significant.

Question #3. What type of model is the most appropriate for this problem? The nonparametric techniques were eliminated in the section titled Model Selection of this chapter. In the section titled Developing the Model in Chapter III the procedures were outlined for selection of the most appropriate parametric model.

Question #4. Which explanatory variables can be identified to predict flight test costs? Personal interviews with flight test engineers and the tests outlined in the section titled Developing the Model of this chapter were used to determine and test the explanatory variables.

Question #5. How accurately can electronic warfare flight test costs be predicted? This question was answered by completing the methodology plan in the section titled Developing the Model and was tested for significance using the tests described in the section titles Validating the Model.

Question #6. Can the model be validated? A minimum level of validation was outlined in the section titled Validating the Model. The dynamic nature of the electronic warfare equipment will require that the data base be updated to ensure it remains valid.

Question #7. Does the model fulfill the needs of the Reconnaissance/Electronic Warfare Systems Program Office? This question will be addressed to the Reconnaissance/ Electronic Warfare Systems Program Office when the model nears completion. At this point the conceptualized model has been approved by expert cost analysts; the plan to use the Aeronautical Systems Division CYBER computer system for the model has also been approved (2,43).

In summary, the methodology adequately provides for the research questions to be answered in a systematic and logical manner.

IV. Findings

Data Control/Outlier Identification

Once the data (see Appendix A) was grouped and checked for accuracy it was reviewed to ensure only the data appropriate for the model being developed was used. Five of the data points were omitted from use in the model development for various reasons. These five data points are shown in the "Outliers" section of Appendix A.

The first two data points (PAVE TAC/FLIR and PAVE TAC/VATS) were omitted because they are both strictly electro optical systems; none of the other systems in the study were designed primarily as electro-optical systems. After identifying these two systems it became apparent that the flight test procedures were different enough that the population of interest could not be broadened to include these two observations. We were also not sure that the cost data collected from the Reconnaisance and Electronic Warfare System Program Office at Wright-Patterson AFB constituted all the flight test costs of these systems.

The JON #2272 WA02 modification to the ALQ 131 system was considered an outlier with respect to the dependent variable flight test costs. The cost of testing this modified system was only $15,000 which was not close to the $151,000 spent to test RR-180 Chaff system, the next least costly project. Because of this disparity (possible Data recording errors) in flight test cost the JON #2272 WA02

modification to the ALQ 131 system was eliminated as a data point.

The two data points associated with the ALQ 172, JON #5615 WA06 and JON #5615 WA07, were not used because this system represented a quantum leap in capability from the other systems represented in the data. The ALQ-172 system was to have the capability to perform the functions of a receiver, jammer and dispenser simultaneously. Because of this leap in capability these two observations were not included in the population. In the data collection phase similar systems being developed for the F-15 and F-16 aircraft were omitted because of incomplete data.

<u>Variable Identification</u>

Independent variables were identified in accordance with the guidance provided in Chapter III under <u>Identification</u>. A Pearson's correlation coefficient matrix (Appendix B) was constructed for the data (Appendix A) in order that the independent variables could be analyzed. If an independent variable was statistically related to flight test costs in a nonsensical manner then that variable was not used; only the variables that were correlated to flight test costs in a logical manner were used to develop the cost estimating models.

Variables identified as candidates for either parametric model are: (Note: the computer codeword is shown in parentheses).

DENSITY (DEN): Flight test costs were expected to vary directly with density because the more dense a system was the more technologically complex it should be; this increased complexity would indicate that flight test costs would need to be greater to fully test a more complex system. The correlation between density and flight test costs was .1020.

MODIFICATION (MOD): Flight test costs were expected to be inversely related to the modification indicator variable because a modified system should require less flight testing than a new system. The correlation between the modification indicator variable and flight test costs was -.4867.

POWER (POW): Total input power was expected to vary directly with flight test costs; if a system had greater input power it would be more likely to be larger, more complex and have increased capabilities that would require a greater testing effort and therefore higher flight test costs. Power and flight test costs were positively correlated at a .2709 level.

RECEIVER (RECD): The receiver indicator variable was thought to have a correlation somewhat lower than that of the Jammer (JXD) Variable. In general, the jammer requires more extensive flight testing than the receivers. However, there was no expectation as to whether RECD would be directly or indirectly related to flight test costs, only that it would have less direct correlation/influence than the JXD Variable. Actual correlation was a -.0618 indicating that very little influence was exerted by the variable.

JAMMER (JXD): The jammer indicator variable was expected to vary directly with flight test costs because jammers generally require more extensive testing than do the other types of electronic warfare equipment. The jammer indicator variable was positively correlated with flight test costs at a .3026 level.

4950th FTW PROJECT (FTW): The 4950th FTW project indicator variable was expected to vary directly with flight test costs. The 4950th FTW usually tests systems that are still in the design phase and have not been developed to the point that they will be ready for operational use after the flight test phase (29). Therefore these projects often require major aircraft modifications and test modifications which are reflected in higher test costs. The correlation between the 4950th FTW project indicator variable and flight test costs was .6904.

TEST YEAR (TESTY): This variable took on the value of the year the flight test was conducted or the value of the middle year in which flight test costs were conducted. In recent years more emphasis has been placed on flight testing of new systems in order that problems can be corrected before "they appear as deficiencies in deployed systems" (12:139); because of this increased emphasis in testing it was expected that flight test costs would vary directly with the test year. However, the actual correlation between test year and flight test costs was -.0930. Further evaluation indicated that a possible cause of the negative correlation may be due

to increased efficiency/proficiency in later testing operations (tests were conducted with the aid of "lessons-learned"). In addition, many of the latter tests were modifications of systems rather than new systems (modifications require less testing therefore less flight test costs). Despite the negative correlation of -.0930 it was decided to keep the TESTY variable.

TECHNICAL YEAR (TECHY): System complexities were expected to increase with the increased technical years which would require higher flight test costs. The positive correlation of .4275 between technical year and flight test costs was as expected.

DENSITY X 4950th FTW PROJECT (DENFTW): This interaction term will give added weight (above the variable DENSITY) to the density of systems tested by the 4950th FTW. Since 4950th FTW systems are tested in the development stage they tend to be less dense than the other systems. Increased density among 4950th FTW systems was also expected to correspond to increased flight test costs. The actual correlation was .843.

VOLUME X MODIFICATION (VOLMOD): This interaction term will increase the weight given to the predictive capability of the volume of modified systems. The variable VOL5 (below) was predicted to be positively correlated with flight test costs because larger sized equipment would normally require more testing. The consensus was that VOLMOD would be inversely correlated with costs because the interaction term would

indicate that for modified programs a larger volume indicated less technological complexity; this complexity would be illustrated by the fact that more recent systems (modifications) are pushed to be less bulky in order for more efficient use in flight; this push for reduced volume would indicate a higher complexity among modified systems. Also this expected negative correlation would tend to measure the absence of the large volumes of 4950th FTW systems, none of which are modifications. The actual correlation between VOLMOD and flight test costs was -.3119.

VOLUME X JAMMER (VOLJXD): This interaction term would indicate that the fact that a system is a jammer makes the importance of the volume variable increase as an indicator of the flight test costs. The impact of the VOLJXD variable was expected to vary directly with flight test costs for the same reason flight test costs would increase with an increase in volume; if a jammer system was greater in volume it was likely to be more complex and to require increased flight testing. The actual correlation between VOLJXD and flight test costs was .2314.

VOLUME X 4950th FTW PROJECT (VOLFTW): The 4950th FTW systems were still in the developmental stage and not compacted into a shape that would allow then to be carried on the operational aircraft the systems were designed for. Often C-141 and KC-135 aircraft were unidentified in order that the system could be flight tested (29). This freedom to not have to restrict a system to a certain size (volume)

meant that the volume of a 4950th FTW tested system was expected to vary directly with flight test costs. The actual correlation was .4945.

(VOLUME)**.5 (VOL5): Flight test costs were expected to increase at a decreasing rate with volume because a greater volume could mean an increased capability in a system that would need to be tested. However, that increased capability was not expected to increase directly with volume since the fixed cost involved in testing a system would be able to be spread over all the flight tests which occurred (7:3). The actual correlation was .2208.

POWER/VOLUME (DPWVOL): This term measures the amount of input power per cubic inch. The term DPWVOL would be expected to be larger for a system of greater capability; therefore, flight test costs were expected to increase directly with an increase in the DPWVOL term. The actual correlation between the two terms was .2052.

(WEIGHT)**.5 (WT5): Flight test costs were expected to increase at a decreasing rate with weight because a greater weight would mean increased system capability that would need to be tested. The increased capability was not expected to increase directly with weight because the fixed costs involved in testing a system would be able to be shared over all the flight tests which occurred (7:3). The actual correlation was .3406.

(WEIGHT)**.5 x TECHNICAL YEAR (WT5TEC): The WT5TEC variable was expected to vary directly with flight test costs

since this term would increase with an increase in technical year or weight. As technical years increase the weight of electronic warfare systems should decrease for a given capability because of electronic technology and the need to decrease the size of electronic warfare systems carried by aircraft. Therefore an increase in weight given an increase or no change in technology would make this interaction term increase and we would expect an increase in flight test costs because the increase in WT5TEC would indicate an increased system capability that must be flight tested. The actual correlation between WT5TEC and flight test costs was .4374.

Linear Regression Specification

After the variables were identified and evaluated for the predicted response with flight test costs a stepwise regression was run using the Statistical Package for the Social Sciences (SPSS). The variables previously identified were used in the SPSS program. The resulting linear regression model was:

C= -5432.48147 + 39.76962 WT5 + 360.85572 RECD + 116657.04676 DENFTW + 68.13108 TECHY - 1875.21334 FTW

C= flight test costs

WT5= (weight)**.5

RECD= receiver

DENFTW= density x 4950th FTW project

TECHY= technical year

FTW= 4950th FTW project

The actual cost and predicted cost using the linear regression model are in Appendix C. The model will be analyzed in Chapter V.

Linear Regression Model Evaluation

A Kolmogorov-Smirnov Test was used to ensure the assumption of a normal distribution of data was not unreasonable (see Appendix D). This assumption was required so that F and T tests could be applied to the linear regression model (28:70,118). The D value for the test was .148 which was less than $d_{22,.05} = .285$; this indicated that accepting the data as being normally distributed was not unreasonable.

A runs test to check the randomness of the data was also accomplished (see Appendix E). Randomness of data points is also a requirement of the linear regression model (28:31,123). The number of runs was eleven (11) which allowed the data to be accepted as random at a 90% level of confidence.

The R^2, and T-Test data from the linear regression model is in Appendix F. The F-Test and Condition Index information is in Appendix G. The R^2 value of .8958 with a corresponding adjusted R^2 value of .8633 indicates that the model would adequately fill the requirements of the Reconnaissance and Electronic Warfare System Program Office, Wright-Patterson AFB for a ballpark estimate of electronic warfare system flight test costs up to six years in advance (2).

As predicted a major area of concern with the model

occurred because of collinearity. Of the variables selected FTW and DENFTW were highly correlated (.935). More moderate correlation was found between TECHY and FTW (.572) and between TECHY and DENFTW (.518). The condition index bounds of 11.420 to 136.921 indicated that there was a very high chance of significant multi-variable collinearity. Variance Inflation Factor Tests (see Chapter III section on Collinearity) were conducted between each independent variable and the remaining independent variables (see Appendix H). When FTW (4950th FTW project was tested against the other independent variables in the linear regression model) a condition index of 11.42 was obtained indicating that some collinearity was present in the model.

Because of the problems with collinearity the usefulness of the model was weakened. Statistical tests may be inaccurate and the correlation coefficients of the model may be related to the dependent variable in a nonsensible manner (28:382-92). Because of this problem it was determined that use of the principal components regression model was appropriate.

Tests and scatterplots were also conducted to test for homoscedasticity. The scatterplots (see Appendix I) did not reveal any major problems with heteroscedasticity. Spearman's Rank Correlation Coefficient Tests (see Chapter III section on Homoscedasticity) were conducted between the independent variables WT5, TECHY and the ranked absolute values of the residuals from the linear regression model.

The results (see Appendices J and K) indicated that there was insufficient evidence to reject the hypothesis that the data was homoscedastic with respect to WT5 and TECHY. The Spearman's correlation coefficient calculated for WT5 was -.289; the Spearman's correlation coefficient calculated for TECHY was .047. Since $R^2{}_{22,.05}$=.359 there is greater than a 90% level of confidence in the data being heteroscedastic with respect to the independent variables WT5 and TECHY. The other variables in the model could not be tested for homoscedasticity because they were either an indicator variable (FTW and RECD) or contained an indicator variable (DENFTW).

The data was tested for autocorrelation with a Durbin-Watson Test (see Chapter III section on Autocorrelation). The calculated value of 2.02299 was well within limits at the 90% confidence level. As a result, no problems with autocorrelation were expected to exist in the model.

Principal Component Analysis Model

Because of the indication of some collinearity in the linear regression model a principal components analysis model was constructed using the BMDP4R statistical package on the CYBER computer. The BMDP4R program selected only thirteen of the sixteen variables for use in the model. Using stepwise regression the model developed was :

Flight Test Costs= -429.990 - 383.980 (MOD) - .070 (POW) + 230.145 (RECD) + 1780.573 (FTW) - 44.138 (TESTY) + 46.093 (TECHY) +.027 (VOLMOD) + .005 (VOLJXD) - .087 (VOLFTW) -

1.002 (VOL5) - 500.982 (DPWVOL)

(cost in thousands of dollars)

MOD = System Modification#

POW = Input Power

RECD = Receiver#

FTW = 4950th Test Wing#

TESTY = Test Year

TECHY = Technological Year

VOLMOD = Volume x Modification@

VOLTXD = Volume x Jamming System@

VOLFTW = Volume x 4950th Test Wing@

VOL5 = (Volume)**.5

DPWVOL = Power/Volume

WT5TEC = (Weight)**.5 x Technological Year

WT5 = (Weight)**.5

Indicator variables

@ Interaction Terms

The R^2 for the model was .8900. A complete summary of the coefficients of the stepwise regression is shown in Appendix L.

A Kolmogrov Test was used to ensure the assumption of a normal distribution of data was not unreasonable (see Appendix M). The D value for the test was .140 which was less than $d_{22,.05} = .285$; this indicated that accepting the data as being normally distributed was not unreasonable.

A Runs Test to check the randomness of the data was also accomplished (see Appendix N). The number of runs was 10 which allowed the data to be accepted as random at a 90% level of confidence.

V. Analysis

Research Questions Answered

The original research problem was to develop a cost estimating model that could be used to estimate long-range flight test costs (up to six years in advance of the actual testing) for electronic warfare equipment. Seven research questions were formulated to help solve the aforementioned problem. At this time, each of the original research questions will be restated with the resulting answers acquired as a result of the research effort.

1. Does the historical data available represent the population to be predicted?

ANSWER: A total of 27 data points were available/ collected (see Appendix A). Of the 27, there were five data points determined to be inappropriate (see Outlier Evaluation Chapter IV). The remaining 22 data points are representative of the population to be predicted (2). Each is either a jammer, receiver, or an expendable (dispenser) electronic warfare system tested; each is either a new or modified system; and each data point includes all the flight test costs associated with the individual system. Therefore, the historical data available and collected are represenative of the population to be predicted.

2. Are the cost estimating (causal) relationships predicted by the experts in the field consistent with the data collected?

ANSWER: The data collected is consistent with the causal relationships predicted by the experts in the field. Each data point was evaluated in detail to ensure causal relationships were consistent (see Variable Identification and Outlier Evaluation Chapter IV).

3. What type of model is the most appropriate for this problem?

ANSWER: A detailed analysis of possible techniques was accomplished to determine the most appropriate technique for this research problem (see Model Selection Chapter III). The parametric techniques of linear regression and principal component analysis were determined to be the most appropriate modeling techniques. A detailed explanation of each considered technique and findings are contained in Chapter III Model Selection.

4. Which explanatory variables can be identified to predict flight test costs?

ANSWER: Over thirty variables were identified initially as potential cost drivers. Each of the variables selected represented information that would likely be available six years prior to flight tests. Of the more than thirty variables identified an initial correlation analysis was conducted to determine (1) those variables which affected the flight test cost in the manner predicted by experts in the field and (2) the variables that had high collinearity.

Sixteen variables were identified that affected flight test costs in the predicted manner (see Variable Identifica-

tion Chapter IV). The determination of causality from system characteristics (such as power, weight, volume, density, technological complexity, type, modification/new system) to the system built and then to the flight test costs of that system was difficult and is somewhat challengeable because of the extrapolation of logic involved.

5. How accurately can electronic warfare flight test costs be predicted with the model and variables selected?

ANSWER: Unfortunately only a statistically based answer is available for this question. The final absolute answer will only be revealed when the actual final costs are compared with the model predictions. However, statistically the models explain 89.58% of the flight test costs with the linear regression model and 89.00% with the principal component analysis model.

6. Can the model be validated?

ANSWER: Due to the limited availability of data, all the data was used to develop the models. Therefore, no full validation process is possible at this time but should be accomplished as soon as additional data points become available. There is no apparent reason why either model could not be subjected to a complete validation procedure at a later date.

7. Does the model fulfill the needs of the Reconnaissance/Electronic Warfare Systems Program Office?

ANSWER: Both models returned results which are satisfactory for the intended use. In predicting flight test

costs several years in advance, a 'ballpark' figure is satisfactory (2).

However, both models have problems associated with them. The linear regression model suffers from high collinearity between important independent variables which resulted in an inability to incorporate several key variables that may have contained additional explanatory information. The principal component analysis model corrected for the collinearity but incorporated so many variables that the logic of the underlying causality became obscure.

The principal component analysis model also is only appropriate for use when point estimates are desired. Confidence intervals can not be made nor can 'tradeoff' analysis be easily accomplished with the principal component model.

Sensitivity of Models To Key Variables

In this section, each model will be analyzed with respect to the incorporated independent variables and how each independent variable responds in the model as compared to the predictions of the experts in the electronic warfare development field.

Key Variables-Regression Model

MODEL:

Flight Test Costs = -5432.481 + 39.770 (WT5) + 360.855 (RECD) + 116657.04 (DENFTW) + 68.131 (TECHY) + 1875.213 (FTW) (cost in thousands of dollars)

WT5 = (weight)**.5

RECD = system was a receiver

DENFTW = density x tested by the 4950th FTW

TECHY = technological year

FTW = tested by the 4950th FTW

All the independent variables respond as predicted by the experts (see Variable Selection Chapter IV). Each has a direct influence on the total flight test cost. The major influences are those systems tested by the 4950th FTW and this is as predicted since the 4950th FTW tests equipment that is in the early conceptual/developmental stages and therefore requires much more extensive testing and test aircraft modifications.

Key Variables-Principal Component Model

MODEL:

Flight Test Costs = -429.990 - 383.980 (MOD) - .070 (POW) + 230.145 (RECD) + 1780.573 (FTW) - 44.173 (TESTY) + 46.093 (TECHY) + .027 (VOLMOD) + .005 (VOLJXD) - .087 (VOLFTW) - 1.002 (VOL5) - 500.982 (DPWVOL) + 7.663 (WT5TEC) - 481.578 (WT5) (cost in thousands of dollars)

MOD = system was a modification

POW = Input Power

RECD = Receiver#

FTW = tested by the 4950th FTW#

TESTY = year the flight test to be accomplished

TECHY = technological year

VOLMOD = volume x modification@

VOLJXD = volume x jamming system@

VOLFTW = volume x tested by the 4950th FTW

VOL5 = (volume)**.5

DPWVOL = power/volume

WT5TEC = (weight)**.5 x technological year

WT5 = (weight)**.5

Indicator variables
@ Interaction terms

The principal component model corrects for collinearity, but the incorporation of so many variables makes the underlying logical inferences between variables obscure. Therefore it was extremely important that only those variables causually related to the dependent variable be included in the model. With this in mind, only those variables predicted by experts as being causually related to flight test costs were selected. Thus, no absolute method of determining the sensitivity exists for this model and therefore the resulting predictions are point estimates only.

VI. Conclusions and Implications

In the past, cost estimating for the flight test costs for electronic warfare systems has been extremely difficult due to the complexity of the systems/process. The complexity is due to rapid technological advances in the electronic warfare field and the requirement to make estimates of flight test costs up to six years in advance of the tests when the program is still in the conceptual phase (only general information is available about the system to be tested).

The two parametric models developed and presented should increase both the accuracy and timeliness of future cost estimates by the Reconnaissance/Electronic Warfare Program Office at Wright-Patterson AFB. However, there are both strengths and limitations that should be considered when using the models.

Strengths

Both models presented will give good point estimates that can be considered 'ballpark' predictions. As a system becomes more fully conceptualized and developed the estimates must be adjusted to reflect the additional information available. Although both models are well suited for long-range estimates, great care must be exercised if estimates are attempted for well defined or fully developed systems. The intent of both models is to ensure estimates are 'realistic' in the early conceptual/developmental periods.

An additional strength of both models is that only general information about the system to be tested is needed to make the cost estimate. This is particularly important since only very general information is available in the early conceptual development.

Next, both models are very easy to use, require little time, and both require only the simplist calculations to develop a cost estimate. However, the estimator must be wary of the ease of calculations and never forget the importance of good common sense/judgement when using the models to develop a cost estimate.

<u>Limitations</u>

Both models give point estimates that are 'ballpark' figures. Thus the estimates are by no means exact and therefore the estimates must be updated continuously as new/revised information becomes available.

In addition, both models assume that past flight test costs are indicative of future flight test costs. If any major changes occur in testing procedures, requirements, or even billing procedures then great care must be used when developing estimates with either model.

The linear regression model also suffers from some collinearity problems. Therefore, not all of the available variables could be used in the model development, and there still exists some collinearity among the remaining variables actually chosen. This problem of collinearity leads to a

small degree of inaccuracy if any use other than point estimates are made with the model. With respect to the principal component model, collinearity has been corrected for but 'tradeoff' analysis has been sacrificed.

Implications For Management

As new data points become available, both models should be updated periodically. Periodic updates will help to insure the cost estimates remain accurate. In addition, a monitering system should be initiated to track actual costs versus the model predictions. Large differences should be investigated to determine the underlying cause. As with any cost estimating technique, there is no substitute for common sense/judgement. If the flight testing requirements change, then modifications/adjustments must be made to the predicted cost estimates.

Recommendations

This section focuses on two areas where changes/additional work is required. The two areas identified could make the process of cost estimating both less costly and more accurate.

First, standardized/required data collection/storage procedures need to be implemented. Useful cost data from past programs/projects is practically nonexistent. The data that is available is kept by nonstandard means and is therefore of little use. Establishment of a 'lessons learned'/final-cost report would be extremely beneficial. Why

'reinvent-the-wheel' everytime a new cost estimate is required? The existing data systems make accurate cost estimates generally too time consuming, inaccurate, and more costly than they should be. Simple guidelines/requirements could pay significant dividends in both time and money saved in this area.

Lastly, it is recommended that the models developed in this document be expanded as soon as practical to include additional types of electronic warfare systems. For instance, some new systems are integrated systems (combination of jammer, receiver, and/or expendables). These types are not appropriate for the present two models presented in this document. Therefore, when data becomes available for the integrated systems a new variable to indicate those systems should be incorporated into the existing models.

Appendix A: Flight Test Data

DATAPT.	SYSTEM	JON#	COST (thousands of dollars)	VOLUME (cubic inches)
1	ALQ 117	2683WA11	1010	17625.6
2	ALQ 117	2683WA12	935	17625.6
3	ALR-69(F-16)	ASDOWA45	896	1690.0
4	Chaff	2683WA06	185	17625.6
5	ALR-56(F-15)	5618WA11	932	4164.0
6	ALR-119 Lens	921AWF21	540	13824.0
7	PECM	N/A(4950th)	1641	16430.4
8	SABRE CROSS	N/A(4950th)	598	26264.3
9	Cross Eye	N/A(4950th)	2907	17266.0
10	Single Axis	N/A(4950th)	1317	48570.0
11	ALQ 131	2272WA03	435	32834.1
12	ALR 69	ASDOWA46	424	1690.0
13	RR-180 Chaff	2274WA04	151	1814.0
14	ALQ 131/CPMS	ASDOWA29	201	32834.1
15	ALQ 131/Receiver	2272WA03	455	32834.1
16	MJB/B10 Flares	2274EA06	498	1814.0
17	Flares (ALE-40)	431GEQ09	180	1814.0
18	ALQ 135	2825WA01	342	10368.0
19	ALQ 94/137	2827WA01	478	13824.0
20	ALR 56(Software)	5618WA07	487	4164.0
21	ALE-45 (F-15)	5618WA13	961	3456.0
22	ALQ-128(F-15)	5618WA14	192	2765.0
		OUTLIERS		
23	PAVE TAC/FLIR	N/A	160	51182.0
24	PAVE TAC/VATS	2056EA06	720	51182.0
25	ALQ 131	2272WA02	15	32834.1
26	ALQ 172	5615WA06	1769	17625.6
27	ALQ 172	5615WA07	2995	17625.6

DATA PT.	WEIGHT (pounds)	DENSITY (lb./cu.in.)	MODIFICATION (yes(y)or no(n)	POWER (input in watts)
1	381.0	.0216	Y	3900
2	381.0	.0216	Y	3900
3	98.5	.0583	N	895
4	381.0	.0216	Y	3900
5	142.6	.0342	Y	680
6	565.0	.0409	Y	10000
7	360.7	.0220	N	8000**
8	375.5	.0143	N	8000**
9	554.0	.0321	N	8000**
10	731.7	.0151	N	8000**
11	573.3	.0175	Y	8200
12	98.5	.0583	N	885
13	37.0	.0204	N	40
14	573.3	.0175	Y	8200
15	573.3	.0175	Y	8200
16	37.0	.0204	Y	40
17	37.0	.0204	Y	40
18	387.0	.0373	Y	8000
19	400.0	.0289	Y	7000
20	142.6	.0342	Y	680
21	170.0	.0492	N	90
22	58.6	.0212	Y	168
OUTLIERS				
23	1277.0	.0250	Y	6000
24	1277.0	.0250	Y	6000
25	573.0	.0175	Y	8200
26	381.0	.0216	N	3900
27	381.0	.0216	N	3900

** Estimated Value

DATA PT.	RECEIVER	JAMMER	DISPENSER	ELECTRO-OPTICAL
1	X			
2	X			
3	X			
4			X	
5	X			
6		X		
7		X		
8		X		
9		X		
10		X		
11		X		
12	X			
13			X	
14		X		
15	X			
16			X	
17			X	
18		X		
19		X		
20	X			
21			X	
22	X			

OUTLIERS

DATA PT.	RECEIVER	JAMMER	DISPENSER	ELECTRO-OPTICAL
23				X
24				X
25		X		
26	X			
27	X			

DATA PT.	TEST YEAR	TECH.YEAR
1	1983	1974
2	1982	1974
3	1982	1980
4	1982	1974
5	1982	1976
6	1980	1974
7	1981	1981
8	1983	1983
9	1982	1982
10	1983	1983
11	1982	1971
12	1982	1980
13	1982	1982
14	1983	1971
15	1982	1971
16	1982	1982
17	1982	1976
18	1983	1976
19	1983	1972
20	1981	1976
21	1983	1983
22	1983	1976
	OUTLIERS	
23	1983	1983
24	1981	1981
25	1981	1971
26	1983	1983
27	1983	1983

*Note: The majority of this data was collected from the 3246th Flight Test Wing, Eglin Air Force Base, Florida. Other sources of data were 4950th Flight Test Wing, Wright-Patterson Air Force Base, Ohio.

Appendix B: Pearson's Correlation Coefficients

	C	DEN	MOD	POW
C	1.000	0.102	-0.487	0.271
DEN	0.102	1.000	-0.311	0.314
MOD	-0.487	-0.311	1.000	0.034
POW	0.271	-0.314	0.034	1.000
RECD	-0.062	0.290	0.179	-0.412
JXD	0.303	-0.213	-0.140	0.856
FTW	0.690	-0.273	-0.624	0.465
TESTY	-0.093	-0.210	-0.066	-0.047
TECHY	0.428	0.221	-0.828	-0.284
DEN FTW	0.843	-0.173	-0.583	0.435
VOLMOD	-0.312	-0.360	0.620	0.485
VOLJXD	0.231	-0.380	-0.214	0.712
VOL FTW	0.495	-0.313	-0.551	0.411
VOL5	0.221	-0.558	0.063	0.845
DPWVOL	0.205	0.457	-0.087	0.583
WT5TEC	0.437	-0.273	-0.059	0.906
WT5	0.341	-0.293	0.070	0.917

	VOL5	DPWVOL	WT5TEC	WT5
C	0.221	0.205	0.437	0.341
DEN	-0.558	0.457	-0.273	-0.293
MOD	0.063	-0.087	-0.059	0.070
POW	0.845	0.583	0.906	0.917
RECD	-0.262	-0.080	-0.299	-0.261
JXD	0.628	0.558	0.727	0.701
FTW	0.455	0.142	0.522	0.396
TESTY	0.180	-0.254	0.063	0.047
TECHY	-0.307	-0.130	-0.194	-0.345
DEN FTW	0.356	0.200	0.487	0.372
VOLMOD	0.590	0.072	0.437	0.571
VOLJXD	0.761	0.181	0.725	0.685
VOL FTW	0.537	0.011	0.547	0.423
VOL5	1.000	0.160	0.919	0.929
DPWVOL	0.160	1.000	0.423	0.427
WT5TEC	0.919	0.423	1.000	0.987
WT5	0.929	0.427	0.987	1.000

	VOLMOD	VOLJXD	VOLFTW
C	-0.312	0.231	0.495
DEN	-0.360	-0.380	-0.313
MOD	0.620	-0.214	-0.551
POW	0.485	0.712	0.411
RECD	0.041	-0.527	-0.315
JXD	0.165	0.837	0.501
FTW	-0.387	0.595	0.884

	VOLMOD	VOLJXD	VOLFTW
TESTY	0.044	0.208	0.191
TECHY	-0.861	0.045	0.534
DENFTW	-0.362	0.465	0.720
VOLMOD	1.000	0.197	-0.342
VOLJXD	0.197	1.000	0.713
VOLFTW	-0.342	0.713	1.000
VOL5	0.590	0.761	0.537
DPWVOL	0.072	0.181	0.011
WT5TEC	0.437	0.725	0.547
WT5	0.571	0.685	0.423

	RECD	JXD	FTW
C	-0.062	0.303	0.690
DEN	0.290	-0.213	-0.273
MOD	0.179	-0.140	-0.624
POW	-0.412	0.856	0.465
RECD	1.000	-0.629	-0.356
JXD	-0.629	1.000	0.567
FTW	-0.356	0.567	1.000
TESTY	-0.055	0.043	0.041
TECHY	-0.226	-0.027	0.572
DENFTW	-0.333	0.530	0.935
VOLMOD	0.041	0.165	-0.387
VOLJXD	-0.527	0.837	0.595
VOLFTW	-0.315	0.501	0.884
VOL5	-0.262	0.628	0.455
DPWVOL	-0.080	0.558	0.142
WT5TEC	-0.299	0.727	0.522
WT5	-0.261	0.701	0.396

	TESTY	TECHY	DENFTW
C	-0.093	0.428	0.843
DEN	-0.210	0.221	-0.173
MOD	-0.066	-0.828	-0.583
POW	-0.047	-0.284	0.435
RECD	-0.055	-0.226	-0.333
JXD	0.043	-0.027	0.530
FTW	0.041	0.572	0.935
TESTY	1.000	0.062	-0.053
TECHY	0.062	1.000	0.518
DENFTW	-0.053	0.518	1.000
VOLMOD	0.044	-0.861	-0.362
VOLJXD	0.208	0.045	0.465
VOLFTW	0.191	0.534	0.720
VOL5	0.180	-0.307	0.356
DPWVOL	-0.254	-0.130	0.200
WT5TEC	0.063	-0.194	0.487
WT5	0.047	-0.345	0.372

Appendix C: Predicted Versus Actual Cost

DATA PT.	SYSTEM (JON#)	LINEAR REGRESSION PREDICTED COST	PRINCIPAL COMPONENTS PREDICTED COST
1	2683WA11	746	792
2	2683WA12	746	836
3	ASDOWA45	773	807
4	2683WA06	385	606
5	5618WA11	581	422
6	921AWF21	555	362
7	PECM	1533	1791
8	SABRE CROSS	786	1479
9	CROSS EYE	2960	2628
10	SINGLE AXIS JAMMER	1184	846
11	2272WA03	357	507
12	ASDOWA46	773	807
13	2274WA04	396	567
14	ASDOWA29	357	463
15	2272WA03	718	573
16	2274EA06	396	232
17	431GEQ09	-13	-325
18	2825WA01	528	1349
19	2827WA01	268	1206
20	5618WA07	581	9
21	5618WA13	741	1668
22	5618WA14	410	418

ERROR TERMS

DATA PT.	ACTUAL COST	LSBF	PRINCIPAL COMPONENTS
1	1010	+264	+218
2	935	+189	+99
3	896	+123	+89
4	185	-200	-421
5	932	+351	+510
6	540	-15	+178
7	1641	+108	-150
8	598	-188	-881
9	2907	-53	+279
10	1317	+133	+471
11	435	+78	-72
12	424	-349	-383
13	151	-245	-416
14	201	-156	-262
15	455	-263	-118
16	498	+102	+266
17	180	+193	+505
18	342	-186	-1007
19	478	+210	-728
20	487	-94	+478
21	961	+220	-707
22	192	-218	-226

Appendix D: Kolmogorov-Smirnov Test for Linear Regression Model

DATA PT.	ASCENDING ORDER i	ORDERED RESIDUAL e_i	$\frac{i}{n}$
12	1	-349	.045
15	2	-263	.091
13	3	-245	.136
22	4	-218	.182
4	5	-200	.227
8	6	-188	.273
18	7	-186	.318
14	8	-156	.367
20	9	-94	.409
9	10	-53	.455
6	11	-15	.500
11	12	+78	.545
16	13	+102	.591
7	14	+108	.636
3	15	+123	.682
10	16	+133	.727
2	17	+189	.773
17	18	+193	.818
19	19	+210	.864
21	20	+220	.909
1	21	+264	.955
5	22	+351	1.000

DATA PT.	$\frac{i-1}{n}$	NORMAL DIST.	|LARGEST DIFF-ERENCE|
12	0	.043	.043
15	.045	.097	.052
13	.091	.113	.023
22	.136	.142	.040
4	.182	.161	.066
8	.227	.176	.097
18	.273	.179	.139
14	.318	.221	.146
20	.367	.323	.086
9	.409	.397	.058
6	.455	.472	.028
11	.500	.648	.148
16	.545	.692	.147
7	.591	.702	.111
3	.636	.729	.093
10	.682	.745	.063
2	.727	.824	.097
17	.773	.829	.056
19	.818	.851	.033
21	.864	.860	.049
1	.909	.903	.052
5	.955	.958	.042

Appendix E: Runs Test (Linear Regression Model)

DATA PT.	RANK ORDER (by Flight Test Cost)	ERROR TERM (+ or -)
13	151	-
17	180	+
4	185	-
22	192	-
14	201	-
18	342	-
12	424	-
11	435	+
15	455	-
19	478	+
20	487	-
16	498	+
6	540	-
8	598	-
3	896	+
5	932	+
2	935	+
21	961	+
1	1010	+
10	1317	+
7	1641	+
9	2907	-

Appendix F: R^2, T-Test for Linear Regression Model

SUMMARY TABLE

STEP	MULTR	RSQ	ADJRSQ	F(EQU)	SIGF	RSQCH	FCH	SIGCH		VARIABLE	BETAIN	CORREL
1									IN:	WTS	0.3406	0.3406
2									IN:	TESTY	-0.1091	-0.0950
3									IN:	MOD	-0.5233	-0.4067
4									IN:	RECD	0.1389	-0.0618
5									IN:	OPNVUL	-0.0064	0.2052
6									IN:	DENFTW	0.0785	0.8431
7									IN:	VOLJXD	-0.2966	0.2314
8									IN:	DEN	0.5581	0.1020
9									IN:	VOLJPI	-0.0763	0.4945
10									IN:	TECHY	0.3698	0.4275
11									IN:	VOLMOD	-0.2914	-0.3119
12									IN:	PUN	-0.5742	0.2709
13	0.9634	0.9282	0.8114	7.951	0.003	0.9282	7.951	0.003	IN:	FTW	-0.8289	0.6904
14	0.9634	0.9281	0.8323	9.884	0.001	0.0000	0.005	0.945	OUT:	TESTY		-0.0950
15	0.9632	0.9277	0.8482	11.668	0.000	-0.0004	0.050	0.828	OUT:	DEN		0.1020
16	0.9627	0.9268	0.8605	13.935	0.000	-0.0009	0.122	0.734	OUT:	OPNVUL		0.2052
17	0.9610	0.9236	0.8663	16.117	0.000	-0.0032	0.488	0.500	OUT:	VOLJXD		0.2314
18	0.9601	0.9218	0.8738	19.108	0.000	-0.0017	0.274	0.610	OUT:	VOLFTW		0.4945
19	0.9589	0.9195	0.8792	22.840	0.000	-0.0024	0.393	0.541	OUT:	MOD		-0.4067
20	0.9549	0.9118	0.8765	25.845	0.000	-0.0077	1.336	0.267	OUT:	VOLMOD		-0.3119
21	0.9465	0.8958	0.8633	27.515	0.000	-0.0160	2.718	0.120	OUT:	PUN		0.2709

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	SE B	BETA	T	SIG T
WTS	39.76962	12.79218	0.45400	3.109	0.0068
RECD	360.85572	113.88308	0.28274	3.169	0.0060
DENFTW	116657.04670	10335.71998	1.65551	7.141	0.0000
TECHY	58.13108	22.59691	0.40758	3.015	0.0082
FTW	-1875.21334	454.06647	-1.17803	-4.520	0.0005
(CONSTANT)	-5432.46147	1885.77156		-2.881	0.0109

Appendix G: F-Test/Condition Bounds for Linear Regression Model

	MEAN	STD DEV	LABEL
C	716.591	628.407	COST
DEN	0.028	0.013	DENSITY
MOD	0.636	0.492	MODIFICATION
POW	4400.364	3734.600	POWER
RECD	0.364	0.492	RECEIVER
JXD	0.490	0.503	JAMMER
FTW	0.182	0.395	4950th
TESTY	82.182	0.795	TEST YEAR
TECHY	77.136	4.313	TECHNICAL YEAR
DENFTW	0.004	0.009	
VOLMOD	9278.005	11569.737	
VOLJXD	9646.132	14168.604	
VOLFTW	4933.214	12113.601	
VOL5	107.787	55.933	
DPWVOL	0.289	0.224	
WT5TEC	1271.643	516.602	
WT5	16.612	6.858	

Number of Cases = 22

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	5	7428831.67170	1485766.33430
RESIDUAL	16	863959.64616	53997.47789

F = 27.51548 SIGNIF F = 0.0000

CONDITION NUMBER BOUNDS: 11.420, 136.921

Appendix H: Variance Inflation Factor Tests

WT5 $\dfrac{1}{1-.6659} = 2.99$

RECD $\dfrac{1}{1-.1822} = 1.22$

DENFTW $\dfrac{1}{1-.8759} = 8.06$

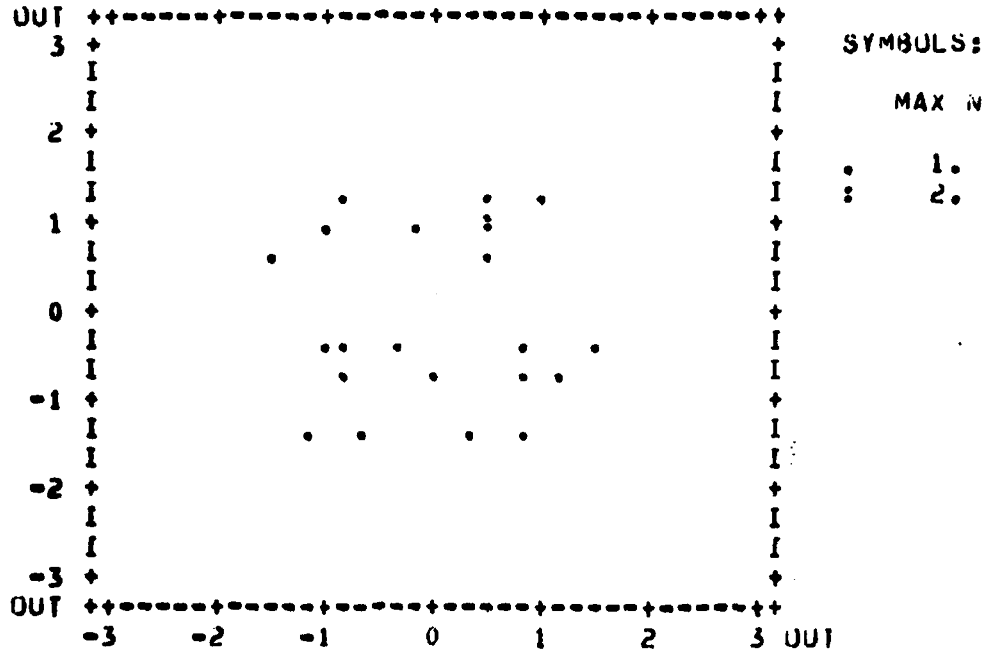
FTW $\dfrac{1}{1-.9124} = 11.42$

TECHY $\dfrac{1}{1-.7293} = 3.69$

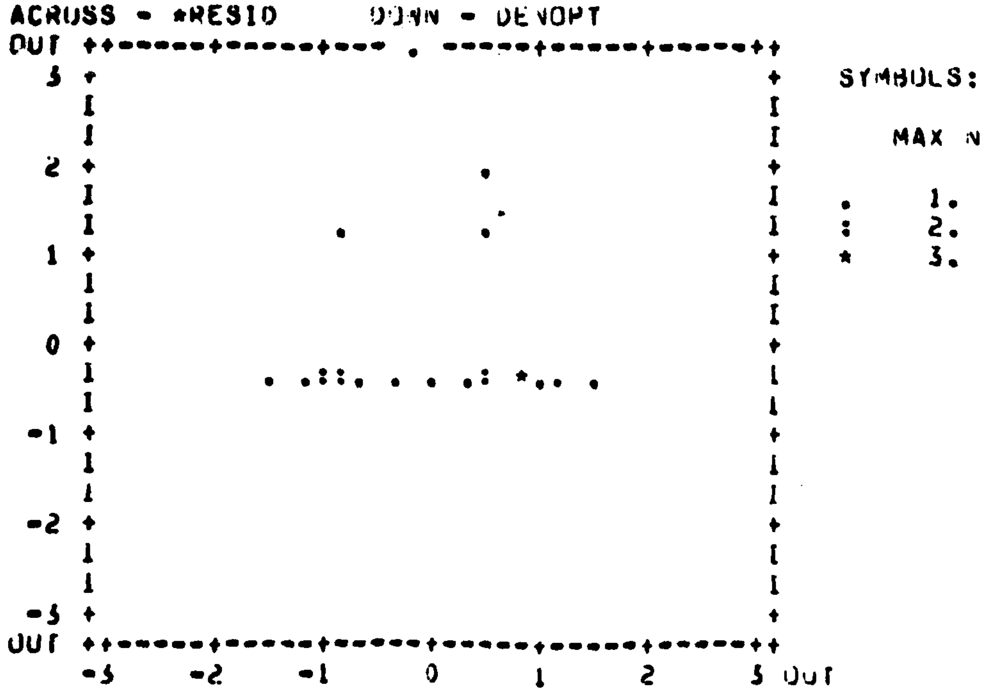
See Variance Inflation Factor Test under Collinearity Chapter III.

Appendix I: <u>Scatterplots for Linear Regression Model</u>

STANDARDIZED SCATTERPLOT
ACROSS - *RESID   DOWN - TECHY



STANDARDIZED SCATTERPLOT
ACROSS - *RESID   DOWN - DEVOPT



```
STANDARDIZED SCATTERPLOT
ACROSS - *RESID      DOWN - OPT
 OUT ++-----+-----+-----+-----+-----+-----++
   3 +                                     +   SYMBOLS:
     I                                     I
     I                                     I      MAX N
   2 +             .   .   :               +
     I                                     I   .     1.
     I                                     I   :     2.
   1 +                                     +   *     3.
     I                                     I
     I                                     I
   0 +                                     +
     I         . .::. . . .: *.. .         I
     I                                     I
  -1 +                                     +
     I                                     I
     I                                     I
  -2 +                                     +
     I                                     I
     I                                     I
  -3 +                                     +
 OUT ++-----+-----+-----+-----+-----+-----++
    -3    -2    -1     0     1     2     3 OUT
```

```
STANDARDIZED SCATTERPLOT
ACROSS - *RESID      DOWN - WTS
 OUT ++-----+-----+-----+-----+-----+-----++
   3 +                                     +   SYMBOLS:
     I                                     I
     I                                     I      MAX N
   2 +                                     +
     I                     .               I   .     1.
     I                                     I   :     2.
   1 +           .  .  .. .                +   *     3.
     I                                     I
     I             *       . : .           I
   0 +                                     +
     I                                     I
     I                .       .  .         I
  -1 +         .           .               +
     I            .                        I
     I            .        . .             I
  -2 +                                     +
     I                                     I
     I                                     I
  -3 +                                     +
 OUT ++-----+-----+-----+-----+-----+-----++
    -3    -2    -1     0     1     2     3 OUT
```

```
STANDARDIZED SCATTERPLOT
ACROSS - *RESID      DOWN - RECD
OUT ++------+------+------+------+------+------++
  3 +                                           +   SYMBOLS:
    I                                           I
    I                                           I      MAX N
  2 +                                           +
    I                                           I   .     1.
    I          . ..    .     . . . .            I   :     2.
  1 +                                           +   *     3.
    I.                                          I
  . I                                           I
  0 +                                           +
    I                                           I
    I             .*.    .. .* :.               I
 -1 +                                           +
    I                                           I
    I                                           I
 -2 +                                           +
    I                                           I
    I                                           I
 -3 +                                           +
OUT ++------+------+------+------+------+------++
    -3     -2     -1      0      1      2      3 OUT
```

Appendix J: Spearman's Rank Correlation Test for Homoscedasticity (WT5) (Linear Regression Model)

DATA PT.	FLIGHT TEST COST RESIDUAL (ei)	RESIDUAL RANK	WT5
5	351	1	11.94
12	349	2	9.92
1	264	3	19.52
15	263	4	23.94
13	245	5	6.08
21	220	6	13.04
22	218	7	7.66
19	210	8	20.00
4	200	9	19.52
17	193	10	6.08
2	189	11	19.52
8	188	12	19.38
18	186	13	19.67
14	156	14	23.94
10	133	15	27.05
3	123	16	9.92
7	108	17	18.99
16	102	18	6.08
20	94	19	11.94
11	78	20	23.94
9	53	21	23.54
6	15	22	23.77

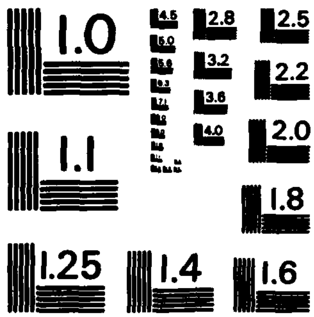
AD-A148 483 COST ESTIMATING MODELS FOR ELECTRONIC WARFARE EQUIPMENT FLIGHT TESTS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. C L HANNA ET AL. SEP 84 2/2

UNCLASSIFIED AFIT/GSM/LSY/84S-15 F/G 14/2 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DATA PT.	WT5 RANK	$\left(\text{RESIDUAL RANK}\right)^2$	$\left(\text{WT5 RANK}\right)^2$	RESIDUAL RANK-WT5 *
5	15.5	1	240.25	15.5
12	17.5	4	306.25	35
1	10	9	100	30
15	3	16	9	12
13	21	25	441	105
21	14	36	196	84
22	19	49	361	133
19	7	64	49	56
4	10	81	100	90
17	21	100	441	210
2	10	121	100	110
8	12	144	144	144
18	8	169	64	104
14	3	196	9	42
10	1	225	1	15
3	17.5	256	306.25	280
7	13	289	169	221
16	21	324	441	378
20	15.5	361	240.25	294.5
11	3	400	9	60
9	6	441	36	126
6	5	481	25	110
		3792	3788	2655

Appendix K: Spearman's Rank Correlation Test for Homoscedasticity (TECHY)

DATA PT.	FLIGHT TEST COST RESIDUAL (ei)	RESIDUAL RANK	TECHY	TECHY RANK
5	351	1	76	11
12	349	2	80	14.5
1	264	3	74	6.5
15	263	4	71	2
13	245	5	82	18
21	220	6	83	21
22	218	7	76	11
19	210	8	72	4
4	200	9	74	6.5
17	193	10	76	11
2	189	11	74	6.5
8	188	12	83	21
18	186	13	76	11
14	156	14	71	2
10	133	15	83	21
3	123	16	80	14.5
7	108	17	81	16
16	102	18	82	18
20	94	19	76	11
11	78	20	71	2
9	53	21	82	18
6	15	22	74	6.5

DATA PT.	(RESIDUAL RANK)^2	(TECHY RANK)^2	RESIDUAL RANK x TECHY RANK
5	1	121	11
12	4	210.25	29
1	9	42.25	19.5
15	16	4	8
13	25	324	90
21	36	441	126
22	49	121	77
19	64	16	32
4	81	42.25	58.5
17	100	121	110
2	121	42.25	71.5
8	144	441	252
18	169	121	143
14	196	4	28
10	225	441	315
3	256	210.25	232
7	289	256	272
16	324	324	324
20	361	121	209
11	400	4	40
9	441	324	360
6	481	42.25	143
	3792	3777.5	2950.5

Appendix L: Principal Component Model Printout

INDEX OF COMPONENTS ENTERING	RESIDUAL SUM OF SQUARES	F-VALUES REGRESSION MODEL	F-VALUES COMPONENT TO ENTER	R^2	CONSTANT	VARIABLES 4 DEN	5 MAD	6 POW	7 RECD
5	.65965E+07	5.14	5.14	.2025	-452.5652	0.0000	-.0000	-.1571	-.0000
12	.51707E+07	5.74	5.24	.3765	-461.4399	0.0000	.0000	-.2425	.0000
1	.40503E+07	6.28	4.98	.5116	-607.6366	0.0000	.0000	-.2406	.0000
2	.31359E+07	6.99	4.96	.6219	-450.6503	0.0000	-.0000	-.2430	.0000
4	.23125E+07	8.28	5.70	.7211	-570.7122	0.0000	-.0000	-.1537	-.0000
10	.19497E+07	8.13	2.79	.7649	-368.9439	0.0000	-383.9799	-.1530	-.0000
11	.16375E+07	8.13	2.67	.8025	-320.8434	0.0000	-383.9799	-.1222	-.0000
3	.13330E+07	8.48	2.97	.8393	-387.3347	0.0000	-383.9799	-.1194	-.0000
7	.11736E+07	8.09	1.63	.8585	-4046.3998	0.0000	-383.9799	-.1176	-.0000
9	.10170E+07	7.87	1.69	.8774	-4160.2093	0.0000	-383.9799	-.1063	230.1454
13	.93482E+06	7.16	.88	.8873	-4090.8604	0.0000	-383.9799	-.0652	230.1454
8	.91354E+06	6.06	.21	.8898	-461.3079	0.0000	-383.9799	-.0709	230.1454
6	.91258E+06	4.98	.01	.8900	-429.9898	0.0000	-383.9799	-.0698	230.1454

8 JXD	9 FTW	10 TESTY	11 TECHY	12 DENFTW	13 VOLMOD	14 VOLJXD	15 VOLFTW
.0000	.0000	.0000	-.0000	0.0000	-.02467	.01099	-.03707
-.0000	1780.5725	.0001	-.0000	0.0000	-.00367	.01852	-.07678
-.0000	1780.5725	.0001	-.0000	0.0000	-.00381	.02875	-.06862
-.0000	1780.5725	.0001	-.0000	0.0000	-.01812	.02442	-.06289
.0000	1780.5725	-.0000	-.0000	0.0000	-.03457	.01627	-.07329
.0000	1780.5725	-.0000	-.0000	0.0000	-.02657	.01555	-.07897
.0000	1780.5725	-.0000	-.0000	0.0000	.00962	.01620	-.09483
.0000	1780.5725	-.0000	-.0001	0.0000	.02133	.00077	-.07600
.0000	1780.5725	-.0000	46.09348	0.0000	.03431	.00046	-.08050
.0000	1780.5725	-.0000	46.09348	0.0000	.02831	.00721	-.08659
.0000	1780.5725	-.0001	46.09348	0.0000	.02179	.00446	-.09121
.0000	1780.5725	-44.13778	46.09348	0.0000	.02292	.00534	-.09031
.0000	1780.5725	-44.13778	46.09348	0.0000	.02696	.00499	-.08661

16 VOL5	17 TECHZ	18 DPWVOL	19 WT5TEC	20 WT5
.04572	0.0000	0.0000	1.69933	.02091
.04536	0.0000	-.00001	1.69084	.02081
.04539	-.0000	-.00001	1.69112	.02081
.04535	-.0000	-.00001	1.69085	.02081
.04556	-.0000	-.00001	1.69868	.02091
.04558	-.0000	-.00001	1.69875	.02091
.20634	-.0000	-.00001	7.62477	-481.57803
.20647	-.0000	-.00001	7.62571	-481.57802
.20650	-.0000	-.00001	7.62597	-481.57802
.20650	-.0000	-.00001	7.62675	-481.57801
.20660	-.0000	-500.98212	7.63036	-481.57796
.20658	-.0000	-500.98212	7.62987	-481.57797
-1.00205	-.0000	-500.98212	7.66264	-481.57797

Appendix M: Kolmogorov-Smirnov Test (Principal Components Model)

DATAPT.	ASCENDING ORDER (i)	ORDERED RESIDUAL (ei)	i	$\frac{i-1}{n}$
18	1	-1007	.045	0
8	2	-881	.091	.045
19	3	-728	.136	.091
21	4	-707	.182	.136
4	5	-421	.227	.182
13	6	-416	.273	.227
12	7	-383	.318	.273
14	8	-262	.367	.318
22	9	-226	.409	.367
7	10	-150	.455	.409
15	11	-118	.500	.455
11	12	-72	.545	.500
3	13	+89	.591	.545
2	14	+99	.636	.591
6	15	+178	.682	.636
1	16	+218	.727	.682
16	17	+266	.773	.727
9	18	+279	.818	.773
10	19	+471	.864	.818
20	20	+478	.909	.864
17	21	+505	.955	.909
5	22	+510	1.000	.955

DATA PT.	NORMAL DIST.	LARGEST DIFFERENCE
18	.017	.028
8	.031	.060
19	.062	.074
21	.067	.115
4	.187	.040
13	.189	.084
12	.209	.109
14	.291	.076
22	.316	.093
7	.375	.080
15	.401	.099
11	.440	.105
3	.575	.030
2	.583	.053
6	.648	.034
1	.677	.050
16	.712	.061
9	.722	.096
10	.841	.023
20	.844	.065
17	.858	.097
5	.860	.140

Appendix N: Runs Test (Principal Components Model)

DATA PT.	RANK ORDER (by FLIGHT TEST COST)	ERROR TERM (+ or -)
13	151	-
17	180	+
4	185	-
22	192	-
14	201	-
18	342	-
12	424	-
11	435	-
15	455	-
19	478	-
20	487	+
16	498	+
6	540	+
8	598	-
3	896	+
5	932	+
2	935	+
21	961	-
1	1010	+
10	1317	+
7	1641	-
9	2907	+

Bibliography

1. Alderman, Captain Kenneth W., USAF. "Techniques of Estimating Costs: The Comparison Process." Unpublished informal report. Aeronautical Systems Division, Wright-Patterson AFB OH, 27 December 1961.

2. Allen, John A., Directorate of Program Control, Deputy for Reconnaissance and Electronic Warfare Systems, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB OH. Personal interview. 10 November 1983.

3. Armstrong, Bruce E. Avionics Data for Cost Estimating. Unpublished paper, Cost library #ACC70.680, November 1976.

4. Bader, Don C. Summary of Selected Aircraft Avionics Production Costs by Functional Avionics Equipment. Unpublished paper, no date, Cost library #ACC 516.650.

5. Barro, S.M., L.B. Early, and M. A. Margolis. Procedures for Estimating Electronic Equipment Costs. Rand Corporation, Santa Monica CA, May 1963.

6. Benoy, David H. and Richard C. Thompson. Flight Test Data for Estimating Flying Hours and Program Costs, An Alternate Approach. Wright-Patterson AFB OH, December 1980.

7. Benoy, David H., Tim G. Loftis, and Grechen L. Kung. Flight Test Data Analysis. Wright-Patterson AFB OH, July 1980.

8. Brewer, Gary D. and Martin Shubik. Models,Simulations, and Games-A Survey. Rand Corporation, Santa Monica CA, May 1972.

9. Bringman, Don. Financial Manager, 4950th Test Wing, Wright-Patterson AFB OH. Telephone interview. 9 January 1984.

10. Bryan, Noreen S. and Roth Clark. "Is Cost Growth Being Reinforced?" Concepts. The Journal of Defense Systems Acquisition Management, 4(2): 105 (Spring 1981).

11. Department of the Air Force. Acquisition Logistics Management. AFLC/AFSC Pamphlet 800-34. Wright-Patterson AFB OH. 12 August 1981.

12. Department of the Air Force. FY 1980 Budget Estimates Research, Development, Test & Evaluation. Washington: HQ USAF, 1980.

13. Department of the Air Force. Research and Development Test and Evaluation. AFR 80-14. Washington: HQ USAF, 10 October 1975.

14. Department of the Air Force. Systems Program Management AFSC Pamphlet 800-3. Andrews AFB Washington DC, 9 April 1976.

15. Department of the Air Force. The Air Force Cost Analysis Program. AFR 173-1. Washington: HQ USAF, 10 October 1975.

16. Dodson, E. N. Parametric Cost Analysis:General Procedures and Extensions General Research Corporation, Santa Monica CA, April 1976.

17. Dodson, E.N., S.F. Kornish, and R.R. Liberman. Cost Analysis of Avionics Equipment. Volume I and II, General Research Corporation, Santa Monica CA.

18. Dryden,J. A. T. Britt, and S. Binnings-DePriester. An Analysis of Combat Aircraft Avionics Production Costs. Rand Corporation, Santa Monica CA, November 1980.

19. Dryden, J.A., T. Britt, S. Binnings-DePriester. Special Duty and Combat Aircraft Avionics Data Base. Rand Corporation, Santa Monica CA, September 1980.

20. DuPre', Lieutenant Thomas J., USAF. A Cost Prediction Model for Electronic Systems Flight Test Costs, MS Thesis LSSR 108-83. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1983, (AD-A135 598).

21. Gordon, Don E. Electronic Warfare-Element of Strategy and Multiplier of Combat Power. New York: Pergman Press, 1981.

22. Gunst, R.F., E.R. Mansfield, and J.T. Webster. "An Analytic Variable Selection Technique for Principal Component Regression," Applied Statistics, 26:34-40, (January 1977).

23. Headquarters Air Force Systems Command. Computerized Cost Estimating Models Catalogue. Cost library #ACC 515.410. Wright-Patterson AFB OH, March 1977.

24. Jeffers, J. N. R. "Two Case Studies in the Application of Principal Component Analysis." Applied Statistics, 16(13): 225-236, (1967).

25. Jess, Stein. The Random House Dictionary of the English Language. New York: Random House, 1981.

26. Kendall, M. G. A Course in Multivariate Analysis. New York: Hafner Publishing Co., 1957.

27. Kenyon, R. E. and S. T. Richards. A Subsonic Military Aircraft Cost Model. General Dynamics, Fort Worth TX, 30 June 1967.

28. Kutner, Michael H., John Neter, and William Wasserman. Applied Linear Regression Models. Homewood IL: Richard D. Irwin, Incorporated, 1983.

29. Linke, Captain Philip W., Electronic Warfare Officer and Flight Test Engineer, 4950th Flight Test Wing, Wright-Patterson AFB OH. Personal interview. 6 January 1984.

30. Manufacturing Technology Division. Air Force Systems Command. Summary Report on the Air Force/Industry Electronics Manufacturing Cost Reduction Study-24 to 29 March 1974. Technical Memorandum AFML-TM-LT-75-2. Wright-Patterson AFB OH: Government Printing Office, 1974.

31. Margolis, Milton A. "Improving Cost Estimation in the Department of Defense," Concepts, The Journal of Defense System Acquisition Management, 4(2): 7 (Spring 1981).

32. Massy, William F. "Principal Components Regression In Explanatory Statistical Research." American Statistical Journal, March 1965

33. Meek, Gary E., Stephen J. Turner. Statistical Analysis for Decision Making. Boston: Houghton Mifflin Company, 1983.

34. Millineaux, Captain Rodney W. J., USAF and Captain Michael A. Yanke, USAF. A Proposed Methodology for the Estimation of Jet Engine Costs in the Early Phases of the Weapon System Acquisition Process. MS Thesis SLSR 2-76A. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, June 1976, (AD-B018 492).

35. Morse, Wayne J. Cost Accounting. Second Edition. Reading MA: Addison-Wesley Publishing Co., 1981.

36. Nagarsenker, Brahmanand N., Professor, Air Force Institute of Technology, Wright-Patterson AFB OH. Personal interview, 23 February 1984.

37. Noah, J. W. Identifying and Estimating R & D Costs. Rand Corporation, Santa Monica CA, May 1962.

38. -----. "A Presentation of the RCA-Price Cost Models," Proceedings of a Conference for Air Force Managers. Wright-Patterson AFB OH, 6 December 1983 .

39. Price, Bertram and Samprit Chatterlee. Regression Analyby Example. New York: John Wiley & Son, 1977.

40. Quade, E.S., ed. Analysis for Military Decisions. Rand Corporation, Santa Monica CA, November 1964.

41. Robbins, Jane, Assistant Professor, Air Force Institute of Technology, Wright-Patterson AFB OH, Personal interview. 19 December 1983.

42. Shiftlet, K. A., Cost/Management Analysis Division, Air Force Flight Test Center, Edwards AFB CA, Telephone interview. 10 January 1984.

43. Spear, Charles, Cost Analyst for Reconnaissance and Electronic Warfare Systems, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB OH, Personal interview. 20 December 1983.

44. Srull, Donald W. "Parametric Cost Estimating Aids DOD in Systems Acquisition Decisions," Defense Management Journal, April 1972.

45. United States Department of Defense. Compendium of Authenticated Systems and Logistics Terms, Definitions and Acronyms. Air Force Institute of Technology, Wright- Patterson AFB OH, 1 April 1981.

VITA

Captain Charles L. Hanna is a fully qualified Electronic Warfare Officer. Prior to his assignment to AFIT, he served eight years as an electronic warfare crewmember and staff officer in the electronic warfare field. His next assignment is to the San Antonio Air Logistics Center at Kelly AFB, Texas, as a cost analyst. Captain Hanna graduated with a Bachelor of Arts degree in Mathematics from the California State University at Fresno in 1973.

Permanent Address: 356 Ridgewood Dr.
Fairborn OH
45324

VITA

Captain John R. Ward is a fully qualified Instructor Weapon Systems Officer. Prior to his assignment to AFIT, he served over seven years as an F-4 Weapon Systems Officer and held various squadron and wing staff positions. His next assignment is to the Air Staff as a cost analyst. Captain Ward graduated with Bachelor of Science degrees in Management and History from the United States Air Force Academy in 1974; he graduated with a Master of Science degree in Human Resources Management from the University of Utah in 1980.

Permanent address: 7506 Cervantes Ct.
Springfield VA
22153

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GSM/LSY/84S-15	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics 6b. OFFICE SYMBOL (If applicable) AFIT/LS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19	

12. PERSONAL AUTHOR(S)
Charles L. Hanna, B.A., Capt, USAF and John R. Ward, M.S., Capt, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
MS Thesis	FROM ____ TO ____	1984 September	110

16. SUPPLEMENTARY NOTATION

Approved for public release: IAW AFR 190-17.
LYNN E. WOLAVER 14 Sept 84
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

17. COSATI CODES		
FIELD	GROUP	SUB. GR.
32	06	3

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Electronic Warfare, Cost Analysis, Cost Estimate, Principal Components, Linear Regression, Flight Test Cost, Project Control

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: Cost Estimating Models for Electronic Warfare Equipment Flight Tests.

Thesis Chairman: Dr. Panna Nagarsenker

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Panna Nagarsenker	22b. TELEPHONE NUMBER (Include Area Code) 513-255-7210 22c. OFFICE SYMBOL AFIT/ENG

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

The project manager is responsible for the cost, schedule and performance of assigned projects. In particular, the cost of a program is under constant scrutiny from the initiation of the program to completion. In order to ascertain the cost effectiveness of a program, a cost estimate must be derived that will act as the cost baseline throughout the program. The initial cost estimate is extremely important because the estimate is used to determine the appropriation of funds necessary to accomplish the project. Inaccurate cost estimates are detrimental to the project and the project manager's capability to manage the project effectively. The ~~paper~~ thesis describes an innovative approach to cost estimating that increases the overall accuracy of a cost estimate while requiring no more manpower than previous methods.

END

FILMED

1-85

DTIC